THREE ESSAYS ON THE LINKS BETWEEN CHRONIC STRESS, SOCIAL PROGRAMS AND PREVENTIVE HEALTH BEHAVIORS AMONG SENIORS IN ENGLAND

By

Andres Ignacio Vecino Ortiz MD MEcon

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Abstract

The increasing rate of behavioral health and chronic conditions, especially in high- and middle-income countries, has brought the issue of chronic stress to the attention of public health researchers. Chronic stress is related to behavioral health and chronic diseases, and recent studies show that its prevalence is increasing.

In the United Kingdom, 47% of adults feel stressed every day, and 59% report feeling more stressed now than 5 years ago. Chronic stress has been difficult to measure in population studies and the impact of population-level interventions on chronic stress is not easily measurable. However, in neuropsychology there has been an increasing trend to use the allostatic load measure as a proxy measure for chronic stress. The allostatic load metric accounts for the degree of wear and tear that is a consequence of higher and sustained levels of psychological and physiological levels of stress.

Chronic stress also may have an effect on decision-making processes. Although the effect of chronic stress on behavioral health and chronic conditions such as through increased endothelium damage and insulin resistance is well known; the impact of chronic stress on preventive behavior is less well understood. The potential consequences of stress on preventive behavior could be better addressed if population-level interventions to reduce chronic stress were put in place, and if individuals at higher risk of chronic stress could be easily identified.

We used a panel survey, the English Longitudinal Survey of Ageing (ELSA), to create the allostatic load metric and to assess 1) the demographic, health and socioeconomic characteristics of seniors in England with higher levels of allostatic load 2) the effect that a social program - the

UK state pension - had on the levels of allostatic load among seniors in England and 3) the effect that the allostatic load had on preventive behavior among seniors in England.

We found that older individuals, people with more comorbidities, people living alone, and those living in households with less than £35,000 of wealth were more likely to have higher levels of allostatic load than their counterparts. We also found that the UK state pension has a statistically significant effect in the reduction of the allostatic load levels among male seniors living in households with less than £35,000 of wealth. Among women of the same wealth category, we found an effect when observing those who live alone and reported not living with a partner. No significant effects were found among those with wealth higher than £35,000. Finally, we found that higher levels of allostatic load reduce preventive behavior, specifically for breast and bowel cancer screening, and increased tobacco consumption.

This dissertation discusses the relevance of measuring chronic stress by using the allostatic load measure to provide empirical evidence on its correlates, its effect on preventive behavior, and how it is affected by a social program.

Keywords: Allostatic load, chronic stress, pension programs, preventive behavior

Thesis Readers:

Antonio Trujillo (Advisor): Department of International Health

David Peters (Committee member): Department of International Health

George Rebok (Committee member): Department of Mental Health

Gerard Anderson (Committee Chair): Department of Health Policy and Management

This dissertation is dedicated to my lovely wife, Maria Cecilia, for her unconditional love and support, even when that entailed living thousands of miles apart or having boring conversations on allostatic load and instruments. I am profoundly grateful for having her along my side during this journey.

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1. Introduction

Despite the abundant evidence on the relationship between stress and behavioral health, not much attention has been paid until recent years to the relationship between stress and other effects outside of behavioral health, including preventive behavior and physical illnesses. The recent interest on stress has revealed, for example, that 50% of Americans report having had at least one significant stressful event in the past year (Robert Wood Johnson Foundation/Harvard School of Public Health 2014). In the United Kingdom, according to the Mental Health Foundation, 47% of adults feel stressed every day, and 59% report feeling more stressed now than 5 years ago (Mental Health Foundation 2013). Chronic stress is also associated with financial concerns; 30% of the population older than 45 reports feeling stress because of difficulties making ends meet (Arber, Fenn, and Meadows 2014).

Factors such as unemployment, globalization, financial and housing insecurity, family instability, climate change and inequality are becoming global factors that no longer predominantly belong to low- and low-middle income countries. Both global and local factors, have become important stressors in higher-middle and high income countries, potentially contributing to the increasing rates of chronic conditions, mental disease and suicide (Ferrari et al. 2014).

Research shows that higher levels of stress are related to a myriad of chronic conditions. Higher levels of chronic stress are related to higher incidence of diabetes (Crews 2007), cardiovascular disease (Sabbah et al. 2008; T. E. Seeman, Singer, et al. 1997), reduced cognition scores (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2002), and all-cause mortality (Crimmins, Kim, and Seeman 2009; Goldman et al. 2006). The physiological mechanism through which chronic stress is hypothesized to cause chronic conditions is mediated by the effect that stress hormones have inducing insulin resistance, reducing the immune response and accelerating endothelium damage (Bruce S. McEwen 2004; T. E. Seeman, Singer, et al. 1997; Seplaki et al. 2004; Dhabhar and McEwen 1999).

Chronic stress has also been established as a cause of impaired decision-making processes. Chronic stress depletes self-control and induces myopic responses (Diamond 2005; Evans and Schamberg 2009; Glanz, Rimer, and Viswanath 2008; Karlamangla et al. 2005; Lindfors, Lundberg, and Lundberg 2006; Muraven and Baumeister 2000; T. E. Seeman, McEwen, et al. 1997). The cognitive consequences of stress have been proven in experimental and empirical settings, in which it is particularly relevant the disproportionate impact stress has on less affluent individuals (Mani et al. 2013).

The cognitive consequences of stress can potentially lead to adverse behaviors towards health, specifically the reduction in preventive behavior by inhibiting individuals to foresee the long-term consequences of behaviors that are harmful towards health. If stress has an effect on preventive behavior, interventions to reduce it have the potential to represent a cost-effective alternative or increasing preventive care and potentially reducing health care costs[1].

Chronic stress is especially important in the senior population. Seniors face constant sources of stress due to a higher likelihood of financial vulnerability as they enter retirement, in addition to the emotional challenges of evolving changes in their societal roles (Rebok, Parisi, and Kueider 2014). Furthermore, some seniors can experience some level of cognitive decline, which reduces the ability to cope with stressful events and carry out a successful ageing process (Rebok, Parisi,

[1] Some studies have shown that not all preventive interventions are cost-effective (Cohen, Neumann, and Weinstein 2008; Kakar 2012), especially among seniors. Therefore, a potential increased uptake to preventive activities as a consequence of decreased stress levels would not necessarily lead to direct health care costs.

and Kueider 2014). As levels of stress increase with age, seniors are also more vulnerable to the health, cognitive and emotional consequences of higher levels of chronic stress, and it is for this reason that stress among seniors represents an important policy concern, especially among the more vulnerable ones.

However, stress in seniors has not received enough attention as a policy. One potential reason is that chronic stress is not easily observable at the population level, and that most of the current strategies to cope with stress focus on individual interventions that have not been addressed, through policy or health systems interventions (Glanz, Rimer, and Viswanath 2008; Rosero-Bixby and Dow 2009). Societal interventions that potentially reduce stress, such as the UK state pension as shown in chapter 3 of this dissertation, might generate previously unmeasured welfare gains by enhancing individual coping skills and improving more broadly the ability of individuals to act, such as on preventive activities as shown in chapter 4 of this dissertation. The challenge in measuring the policy relevance of stress might lead to underestimating the potential welfare gains (measure as the sum of all individual utilities) of policy interventions that affect stress levels. Future research derived from this dissertation work might include welfare analysis studies that account for the impact on stress levels and their more distant effects in different outcomes including mortality, similar to what has been done for Medicare in the US (Finkelstein and McKnight 2008; Gruber and Levy 2009; Barcellos and Jacobson 2015).

The issue that chronic stress has previously been unobservable has been addressed by recent studies in neuropsychology, which have measured chronic stress using a measure known as the allostatic load. Allostatic load is a summary measure for psychological and physical stress in which a set of biomarkers such as C-reactive protein or blood pressure signal a chronic physiological response to stress, including psychosocial stress and disease itself (T. E. Seeman, Singer, et al.

1997; Teresa E. Seeman et al. 2001). The allostatic load measure is derived from the physiological changes of the stress response.

The stress response is commonly known to have two phases, in which the stressors generate a primary and a secondary appraisal (Glanz, Rimer, and Viswanath 2008). The primary appraisal constitutes the initial judgment the individual makes about the threat, which might be affected by prior experience. The secondary appraisal is comprised by the judgment of the individual about her/his ability to change the threatening situation. The regulation of both the primary and secondary appraisal is modulated by the individual's coping strategies, which attempt to change the threatening situation as well as to provide emotional regulation. The combination of the primary and secondary appraisal, and the coping strategies reflect the final response of the individual to the stressor (Glanz, Rimer, and Viswanath 2008). During all these phases, the body experiences a physiological response in which it prepares itself to respond to the threat by activating the hypothalamic-pituitary-adrenal axis and the sympathetic nervous system. Such response is determined by genetic predisposition, the early childhood environment (Dahl 2004); and naturally, the perceived nature of the stressor. The stress response must switch off when the threat is over as these physiological changes represent a higher level of allostasis or "wear and tear" of the body (Bruce S. McEwen 2000). Although adaptive stress implies the activation and deactivation of the system when appropriate, chronic increase in allostasis occurs when there is a non-adaptive stress response. Four different types of non-adaptive stress response have been identified: 1) continued stress response to repeated stressor events, 2) lack of adaptation to a continued stressor event, 3) prolonged response due to delay in shutting down the stress response, 4) excessive or inadequate stress response (Gerin and Pickering 1995; Kirschbaum et al. 1995).

Biomarkers that either modulate or that become the consequence of higher levels of allostasis are then measured and counted in order to create the allostatic load measure. Biomarkers used to build the allostatic load metric mostly take into account five dimensions of the stress response: 1) Cardiovascular activity, measured through the systolic and diastolic blood pressure, creatinine clearance, peak respiratory flow, and heart rate. 2) Glucocorticoid activity is obtained by measuring the levels of cortisol, HDL, total cholesterol, triglycerides, glycated hemoglobin, glucose, albumin, homocysteine, BMI and the waist-hip ratio. 3) Sympathetic activity is measured through the levels of epinephrine and norepinephrine; 4) Hypothalamic-pituitary-adrenal axis activity is measured through the levels of serum dihydroepiandrosterone sulfate (DHEA-S), which is an antagonist of the axis. 5) Finally, fibrinogen and the C-reactive protein is a proxy for immune and inflammatory activity. (Read and Grundy 2012).

The advantage of the allostatic load is that it measures chronic stress using an objective metric without the nuances that are usually present with self-reported stress studies (Rosero-Bixby and Dow 2009; Gardner and Oswald 2004) or through indirect measures such as exposure to war (Costa and Kahn 2010). The allostatic load is a succinct single metric that summarizes a very complex physiological response. It is a widely accepted proxy indicator to measure stress using a measure of physiological parameters (Bruce S. McEwen 2000; T. E. Seeman, McEwen, et al. 1997; Juster, McEwen, and Lupien 2010).

The availability of this measure has allowed prior studies to determine the effect that chronic stress has on chronic conditions (Bruce S. McEwen 2004; T. E. Seeman, Singer, et al. 1997; Seplaki et al. 2004; Dhabhar and McEwen 1999), mortality (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2005; Teresa E. Seeman et al. 2001), and impaired decision-making processes (Kado et al. 2005; Karlamangla et al. 2002; Seplaki et al. 2004; Lindfors, Lundberg, and Lundberg 2006;

Diamond 2005; T. E. Seeman, McEwen, et al. 1997; Lindfors, Lundberg, and Lundberg 2006; Evans and Schamberg 2009; Diamond 2005; Karlamangla et al. 2005; T. E. Seeman, McEwen, et al. 1997).

The first construct validity study using the allostatic load measure was made by Seeman et al (T. E. Seeman, Singer, et al. 1997) in which they showed the gradient existing between the allostatic load measure as a proxy for stress and the cognitive and functional scores of a sample of seniors in the US. Factor analysis has been conducted with the allostatic load measure, showing that it is comprised by one single underlying factor (Howard and Sparks 2016), evidencing the unidimensionality of the measure when being used to measure chronic stress at the population level. In terms of predictive validity, the allostatic load has proved to predict functionality, mortality, and cognition (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2002; Crimmins, Kim, and Seeman 2009; Goldman et al. 2006). One study found that 35.4% of the variance in mortality risk attributable to education is captured by the effect of the allostatic load (Teresa E. Seeman et al. 2004)

Regarding reliability of the allostatic load measure, one study found that the test-retest reliability of allostatic load comparing it with the Trierer Inventory of Chronic Stress produces an intraclass correlation coefficient of 0.89 (Wippert et al. 2014). Internal consistency studies show that the Alpha internal consistency reliability score of the allostatic load measure reaches 0.79 (Goldman et al. 2005).

The body of research on chronic stress and allostatic load has consistently shown a relationship between external stressors, individual factors and the behavioral responses with the allostatic load measure (B. S. McEwen 1998). A literature review carried out by Juster et al (Juster, McEwen, and Lupien 2010) shows that the body of research on allostatic load has produced reliable and consistent results ranging from assessing the stress caused by racial differences (Geronimus et al. 2006) to the effectiveness of anxiolytic drugs on cognition and stress (Soria et al. 2015).

This dissertation project takes advantage of the allostatic load measure assessed in a nationally-representative population survey of non-institutionalized seniors in England to provide empirical evidence on: 1) the demographic, socioeconomic, and health characteristics of individuals with higher levels of allostatic load. 2) The effect that a social program (the UK state pension) has on allostatic load levels. 3) The effect that allostatic load levels have on preventive behavior.

In many cases, public health has relied on syndemics to understand disease and social conditions not as isolated circumstances, but as part of a complex system that requires a broader societal perspective (Singer 2009). Prior examples of syndemics are the cases of tobacco control (Wynder and Hoffmann 1979), HIV prevention (Gupta et al. 2008), and obesity (Weisberg SP 2002). Chronic stress has been traditionally investigated from a purely individual perspective despite prior literature showing a consistent relationship of chronic stress with demographic, socioeconomic, and health conditions, (Bruce et al. 2013; Catalano 2009; Chrousos GP and Gold PW 1992; Goh, Pfeffer, and Zenios 2015; Rosengren et al. 1993; Juster, McEwen, and Lupien 2010). This dissertation study attempts to apply a syndemic approach to address the links between stress, social programs, and preventive behaviors in England. With that objective, this dissertation will try to identify characteristics of English seniors with higher levels of allostatic load, to evaluate a potential policy that can have an effect on the levels of allostatic load, and finally the effects on preventive behavior that the higher levels of allostatic load entail. This dissertation will focus on the following three specific aims, which are summarized in table 1.1:

1. **Aim 1: Who experiences higher levels of chronic stress? The correlates of the allostatic load among seniors in England.**

   The first paper assesses the determinants of higher levels of allostatic load among seniors in England using summary statistics.

2. **Aim 2: Do pension programs reduce chronic stress levels among seniors in England?**

   This paper evaluates the effect of a social program - the UK state pension - on the levels of allostatic load among seniors in England.

3. **Aim 3: Does chronic stress affect preventive behavior among seniors in England?**

   This paper investigates the effect that the levels of allostatic load have on preventive behavior among seniors in England using an instrumental variables model.

Table 1.1 Summary of the dissertation aims

Title	Aims	Outcome	Methods	Findings
Who experiences higher levels of chronic stress? The correlates of the allostatic load among seniors in England.	To explore the correlates of allostatic load and their trends.	Allostatic load	Summary statistics, and linear regression model	Higher levels of allostatic load among seniors in more vulnerable conditions such as those living alone and in less wealthy households, without a partner, with more comorbidities and lower cognition scores.
Do pension programs reduce chronic stress levels among seniors in England?	To explore the effect that the UK state pension has on allostatic levels	Allostatic load	Regression discontinuity design	The UK state pension reduces the levels of allostatic load among seniors living in more vulnerable conditions.
Does chronic stress affect preventive behavior among seniors in England?	To understand the effect that the allostatic load has on three preventive behaviors	Smoking, breast cancer screening and bowel cancer screening	Instrumental variables model	The allostatic load reduces the levels of breast and bowel cancer screening. It also increases the levels of smoking.

2. Who experiences higher levels of chronic stress? The correlates of the allostatic load among seniors in England

Abstract

Previous research shows that the burden of stress has increased in recent years. Factors such as unemployment, globalization, financial and housing insecurity, family instability, climate change and inequality affect both developing and developed economies increasing the levels of stress, especially among the more vulnerable populations. We study the factors related to seniors facing higher levels of stress using the allostatic load measure in a nationally representative survey of English seniors (English Longitudinal Survey of Ageing). This paper shows that stress constitutes a factor that can be related to individual, social and economic conditions and therefore a factor that can be potentially affected by social programs and health policies. This paper provides evidence to suggest policy actions from a government perspective, and it highlights more generally the value of using biomarker data to assist policy makers.

2.1 Introduction

In recent years, there has been a growing interest on stress in the public health field. Factors such as unemployment, globalization, financial and housing insecurity, family instability, climate change and inequality are becoming global factors that no longer predominantly belong to low and low-middle income countries. These global factors, in addition to local issues, have become important sources of stress in higher-middle and high income countries, which have been evidenced by the increasing rates of chronic conditions, mental disease and suicide (Ferrari et al. 2014). The interest in stress in public health is fairly recent despite that the health impacts of stress have been discussed in psychology for a long time (Schar, G, and M 1973). Chronic stress has shown to be related to multiple adverse health outcomes, especially for chronic conditions. Higher levels of chronic stress are related to higher incidence of diabetes (Crews 2007), cardiovascular disease (Sabbah et al. 2008; T. E. Seeman, Singer, et al. 1997), reduced cognition scores (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2002), and all-cause mortality (Crimmins, Kim, and Seeman 2009; Goldman et al. 2006). This is particularly important for seniors as these stressors affect the four dimensions (physical, cognitive, emotional, and behavioral) of the key factors for a successful ageing process (Rebok, Parisi, and Kueider 2014).

Chronic stress is hypothesized to be a direct cause of chronic conditions by accelerating damage to the endothelium and therefore increasing the risk of atherosclerosis (Bruce S. McEwen 2004; T. E. Seeman, Singer, et al. 1997; Seplaki et al. 2004). It also increases insulin resistance due to the permanent higher levels of cortisol, and reduces the immune response (Dhabhar and McEwen 1999) . However, chronic stress also can affect health through indirect ways by reducing the ability of individuals to engage in healthy behaviors. Chronic stress can reduce self-efficacy, which is an important factor for engaging in preventive behavior (Bandura 2010; Cherrington et al. 2011; Floyd, Prentice-Dunn, and Rogers 2000; Jayanti and Burns 1998). Chapter 4 of this dissertation provides evidence that suggests a potential link between chronic stress and the reduction of preventive behavior, specifically the demand for screening for breast cancer and smoking. Other research suggests that chronic stress can be a potential mediator in the relationship between ethnic differences and chronic conditions (Jackson, Knight, and Rafferty 2010), and that also affects other aspects of behavior such as job control (Li et al. 2007) and socioeconomic status (Dowd and Goldman 2006; Worthman and Panter-Brick 2008).

Despite this literature, the difficulty of measuring the magnitude and incidence of chronic stress at the population level is likely responsible for the fact that research on this topic using large population-based studies has not been carried out very often. Fortunately, neuropsychologists have in their toolset a strategy to measure chronic stress through physiological biomarkers that signal either the stress response or the chronic consequences of the stress reaction. This set of biomarkers is commonly called allostatic load and represents the level of 'wear and tear' of the body when the body responds chronically to stress (Juster, McEwen, and Lupien 2010; B. S. McEwen and Stellar 1993; T. E. Seeman, Singer, et al. 1997).

Taking advantage of the allostatic load measure, we provide data on the relationship that allostatic load, as a proxy for chronic stress, has on different demographic, socioeconomic, and health indicators among seniors in England. Assessing chronic stress levels in the senior population is very important. Seniors face constant sources of stress due to a higher likelihood of financial vulnerability as they move towards and enter retirement. There is also the emotional challenges of evolving changes in societal roles. In addition, because some seniors can experience some level of cognitive decline, they face a reduced ability to cope with stressful events, which makes them more vulnerable to the health, cognitive and emotional consequences of higher and more persistent levels of stress. It is for this reason that stress among seniors represents an important policy concern (Rebok, Parisi, and Kueider 2014).

To carry out this research, we use the English Longitudinal Survey of Ageing (ELSA), which is a nationally-representative longitudinal survey carried out in England over an 11-year period among non-institutionalized individuals older than 50. This survey includes biomarkers measurement, allowing us to measure the allostatic load levels of this population.

In this study, we found that our variable for chronic stress, the allostatic load metric, increases with age and that there are no significant differences by gender. Higher levels of allostatic load were found among seniors in more vulnerable conditions such as those living alone, in less wealthy households, without a partner, with less health and lower cognition scores.

This paper shows that chronic stress constitutes a factor that can be affected by individual, social and economic conditions and therefore a factor that can be potentially affected by social programs and policies. The results of this research suggest that more research should be done on the consequences of chronic stress, while stressing the fact that the burden of stress constitutes one more expression of inequalities among seniors.

2.2 The allostatic load metric as a proxy for stress

In this research study, the allostatic load measure has been taken as the approach to measure stress given that it is a valid and reliable, well-accepted and measurable method (Goldman et al. 2005; Wippert et al. 2014; Teresa E. Seeman et al. 2004; Howard and Sparks 2016; T. E. Seeman, Singer, et al. 1997; Gersten 2008). The allostatic load metric is an empirical tool that signals the neuroendocrine response of the body to chronic psychological and physical stress (T. E. Seeman, Singer, et al. 1997; Teresa E. Seeman et al. 2001). The advantage of that metric is that is a suitable way to measure stress with an objective metric without the nuances that are usually present with self-reported stress (Rosero-Bixby and Dow 2009) or through indirect measures (Costa and Kahn 2010). Moreover, it is a validated and succinct single metric that comprises a very complex response (Bruce S. McEwen 2000; T. E. Seeman, McEwen, et al. 1997). Higher and persistent levels of stress increase the rate of allostasis, the wear and tear of the body, and the byproducts of such higher allostasis rate can be observed using a set of biomarkers (Juster, McEwen, and Lupien

2010). Biomarkers used to build the allostatic load metric mostly take into account five dimensions of the stress response: 1) Cardiovascular activity, measured through the systolic and diastolic blood pressure, creatinine clearance, peak respiratory flow, and heart rate. 2) Glucocorticoid activity is obtained by measuring the levels of cortisol, HDL, total cholesterol, triglycerides, glycated hemoglobin, glucose, albumin, homocysteine, BMI and the waist-hip ratio. 3) Sympathetic activity is measured through the levels of epinephrine and norepinephrine; 4) Hypothalamic-pituitary-adrenal axis activity is measured through the levels of serum dihydroepiandrosterone sulfate (DHEA-S), which is an antagonist of the axis. 5) Finally, fibrinogen and the C-reactive protein is a proxy for immune and inflammatory activity. (Read and Grundy 2012).

The first construct validity study using the allostatic load measure was made by Seeman et al (T. E. Seeman, Singer, et al. 1997) in which they showed the gradient existing between the allostatic load measure as a proxy for stress and the cognitive and functional scores of a sample of seniors in the US. Factor analysis has been conducted with the allostatic load measure, showing that it is comprised by one single underlying factor (Howard and Sparks 2016), evidencing the unidimensionality of the measure when being used to measure chronic stress at the population level. In terms of predictive validity, the allostatic load has proved to predict functionality, mortality, and cognition (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2002; Crimmins, Kim, and Seeman 2009; Goldman et al. 2006). One study found that 35.4% of the variance in mortality risk attributable to education is captured by the effect of the allostatic load (Teresa E. Seeman et al. 2004).

Regarding reliability of the allostatic load measure, one study found that the test-retest reliability of allostatic load comparing it with the Trierer Inventory of Chronic Stress produces an intraclass correlation coefficient of 0.89 (Wippert et al. 2014). Internal consistency studies show that the Alpha internal consistency reliability score of the allostatic load measure reaches 0.79 (Goldman et al. 2005).

A literature review carried out by Juster et al (Juster, McEwen, and Lupien 2010) shows that the body of research on allostatic load has produced reliable and consistent results ranging from assessing the stress caused by racial differences (Geronimus et al. 2006) to the effectiveness of anxiolytic drugs on cognition and stress (Soria et al. 2015).

2.3 Data and study sample

We are using data from the English Longitudinal Study of Aging (ELSA). ELSA is a 6-wave nationally representative longitudinal survey of the non-institutionalized population above 50 in England jointly conducted by the University College of London, the Institute for Fiscal Studies, and the National Center for Social Research based on the Health Survey for England (Marmot et al. 2003; Phillips et al. 2012). We are using this survey because it includes biomarker information for the individuals assessed in waves 2, 4 and 6 (2005, 2009 and 2013), which allows us to create an allostatic load metric as a proxy for chronic stress.

The initial ELSA sampling framework was based on all the households that responded the Health Survey for England (HSE) of 1998, 1999, or 2001 with a total of 23,132 households interviewed. HSE is a cross-sectional nationally representative survey of the non-institutionalized population conducted every two years to assess the health status of the population of England. The HSE population involves a multistage probability sampling approach based on postal codes and households (English Longitudinal Survey of Ageing 2001; Rachel Craig and Jennifer 2014). Of all the households that responded these three HSE surveys, all households with at least one eligible member were defined as eligible households in the ELSA survey. An eligible member was defined as anyone in the household born before February 29th, 1952 (17,744 individuals) and who agreed to be re-contacted (11,391 individuals). Younger partners of eligible household members were also included in the survey, but they are not included in our study since they are not being taken samples for assessment of biomarkers. Potential biases are introduced by this condition, especially the possibility of self-selection by capturing healthier individuals who are more likely and more willing to be re-contacted.

All eligible individuals (n=11,391 at wave 1) were contacted and followed up during six biennial waves when possible. Of the initial 11,391 eligible individuals at wave 1, 8,781 (82%) were followed-up during the second wave, when the first round of biomarkers samples were taken. Subsequent cohorts of individuals ("refreshment samples") from the HSE were added in 2007 at wave 3 (n=1,276), in 2009 at wave 4 (n=1,219) and in 2013 at wave 6 (n=2,253) in order to maintain a representative sample of the population older than 50 given the attrition of the survey.

The ELSA survey included biometric and anthropometric measurements at wave 2, 4 and 6. In each of the waves, all the participants who did not have an exclusion criterion for performing biometric and/or anthropometric measures were invited to schedule a nurse visit to be part of the "nurse subsample", where all biometric and anthropometric measurements were taken. The exclusion criteria were 1) Not providing written consent for the measurements; 2) The participant was on anticoagulant medication or had a clotting or bleeding disorder (for blood samples). In addition to these exclusion criteria, for blood samples requiring fasting, they were not taken on respondents who 1) were over 80 years old; 2) seemed frail or ever had a seizure; or 3) the nurse had concerns about asking them to fast for any other specific health concern. Fasting was defined as having had any food or drink except water five hours prior to the blood test (de Oliveira et al. 2008). Once again, the bias introduced by the eligibility criteria for the biometric and anthropometric measurements to enroll healthier subjects will be assessed in this study.

This research study included all the individuals present in waves 2, 4, or 6, including those included in the refreshment samples that were willing and fit enough to provide biomarker samples. Of the 24,187 individuals present in the three waves, 18,828 had blood samples and anthropometric measurements taken, and therefore these individuals comprise the study sample used in this research study (6,215 for wave 2; 6,433 for wave 4; and 6,180 for wave 6). More information on the ELSA survey can be found in the internal ELSA documentation (Marmot et al. 2003; Phillips et al. 2012) or in the ELSA website at www.elsa-project.ac.uk . Specific weights for the subsample of individuals with biomarkers taken are available in the dataset and used accordingly. In table 2.1, we are displaying the descriptive statistics of the allostatic load and the independent variables. Table 2.1 also displays the differences (and the p-values) between the respondents with and without biomarker samples.

The ELSA survey is publicly available through online registration and acceptance of the terms and conditions (Erens and Primatesta 1999; Prior et al. 2003; Taylor, Conway, and Lessof 2003). The Institutional Review Board (IRB) of the Johns Hopkins School of Public Health determined this research project and the data proposed to be used as “not human subjects research” on December 3rd, 2014 and therefore it does not require IRB oversight.

2.3.1 Sample selection bias

Given that only seniors who were fit enough to undergo the biomarker tests and who agreed to be tested are included in this sample, we are likely using a subsample of younger, healthier, wealthier, more likely to be working, more likely to be living with a partner, and more educated. Table 2.1 shows the differences between the study sample and the full sample with all the individuals included in the ELSA survey across the three waves (including those who do not have biomarker measurements). The study sample includes 78% of the full sample. This type of sample selection bias is inherent to conducting research using biomarkers in senior populations. The selection bias in our study sample is likely to bias downwards the effects found during this study, as the population we are observing is generally more affluent and healthier than the general population. Any relationship of the independent variables with the allostatic load is therefore likely to be equal or smaller than what would have been seen in a less healthy population (T. E. Seeman, Singer, et al. 1997; Teresa E. Seeman et al. 2001).

Table 2.1 Descriptive statistics for the independent variables and the allostatic load measure

Variables	Wave 2		Wave 4		Wave 6		Full sample		
	n	%	n	%	n	%	*n*	%	*p*
Allostatic load									
0	1,511	24.3	1,510	23.5	1,471	23.8	6,779	28.0	
1-2	2,825	45.5	2,952	45.9	2,800	45.3	10,982	45.4	
3-4	1,432	23.0	1,551	24.1	1,499	24.3	5,129	21.2	N/A
More than 4	447	7.2	420	6.5	410	6.6	1,303	5.4	
Age									
50-59	1,976	31.8	1,876	29.2	1,444	23.4	6,692	27.7	
60-69	2,129	34.3	2,487	38.7	2,527	40.9	8,759	48.2	<0.01
70-79	1,456	23.4	1,498	23.3	1,608	26.0	6,058	33.3	
80 or more	654	10.5	572	8.9	601	9.7	2,684	14.8	
Sex									
Male	2,829	45.5	2,910	45.2	2,770	44.8	10,888	45.0	0.27
Female	3,386	54.5	3,523	54.8	3,410	55.2	13,305	55.0	
Region									
North-East	424	6.8	407	6.3	372	6.0	1,537	6.4	
North-West	802	12.9	701	10.9	694	11.2	2,777	11.5	
Yorkshire and the Humber	665	10.7	703	10.9	668	10.8	2,604	10.8	
East Midlands	605	9.7	640	9.9	674	10.9	2,562	10.6	
West Midlands	681	11.0	749	11.6	686	11.1	2,639	10.9	0.83
East of England	743	12.0	810	12.6	768	12.4	3,050	12.6	
London	511	8.2	540	8.4	489	7.9	2,023	8.4	
South-East	1,046	16.8	1,125	17.5	1,070	17.3	4,121	17.0	
South-West	736	11.8	758	11.8	759	12.3	2,874	11.9	

Note: Each column includes participants aged 50 to 99 and displays the descriptive statistics of each of the independent variables for all individuals included in the study sample (n=18,828 respondents) by wave. The full sample column includes all 24,187 individuals in the survey and the p-value represents the results of a bivariate test depicting the differences between the full sample and the study sample. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. 1 Great Britain Pound (GBP) is equivalent to approximately 1.4 USD. The education variable has eight categories from the National Vocational Qualification of England: no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate). Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis.

Table 2.1 Descriptive statistics for the independent variables and the allostatic load measure (cont.)

Variables	Wave 2		Wave 4		Wave 6		Full sample		
	n	%	n	%	n	%	*n*	*%*	*p*
Marital status									
Living without partner	1,954	31.4	2,096	32.6	2,082	33.7	8,040	44.3	<0.01
Living with partner	4,260	68.6	4,334	67.4	4,095	66.3	16,144	88.9	
Size of the household									
0	1,423	22.9	1,375	21.4	1,332	21.6	5,459	22.6	
1	3,718	59.8	3,562	55.4	3,486	56.4	13,694	56.6	
2	736	11.8	873	13.6	803	13.0	3,047	12.6	0.09
3-4	307	4.9	563	8.8	519	8.4	1,821	7.5	
More than 4	31	0.5	60	0.9	40	0.6	172	0.7	
Retired									
Yes	3,257	52.4	3,660	59.2	3,175	59.2	13,538	56.0	<0.01
No	2,958	47.6	2,520	40.8	2,190	40.8	10,655	44.0	
Education level									
No qualification/other	2,322	37.7	1,993	31.3	1,594	28.8	7,862	43.3	
Foreign	513	8.3	420	6.6	345	6.2	1,650	9.1	
NVQ1	288	4.7	241	4.1	213	#REF!	981	5.4	
NVQ2	1,109	18.0	1,261	19.8	1,135	20.5	4,375	24.1	<0.01
NVQ3	411	6.7	502	7.9	458	8.3	1,700	9.4	
NVQ4	768	12.5	891	14.0	820	14.8	3,119	17.2	
NVQ5	754	12.2	1,058	16.6	972	17.6	3,459	19.0	

Note: Each column includes participants aged 50 to 99 and displays the descriptive statistics of each of the independent variables for all individuals included in the study sample (n=18,828 respondents) by wave. The full sample column includes all 24,187 individuals in the survey and the p-value represents the results of a bivariate test depicting the differences between the full sample and the study sample. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. 1 Great Britain Pound (GBP) is equivalent to approximately 1.4 USD. The education variable has eight categories from the National Vocational Qualification of England: no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate). Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis.

Table 2.1 Descriptive statistics for the independent variables and the allostatic load measure (cont.)

Variables	Wave 2		Wave 4		Wave 6		Full sample		
	n	%	n	%	n	%	*n*	%	*p*
Total household wealth (GBP)									
Less than 35,000	3,271	54.9	2,988	48.5	2,629	44.2	11,735	64.6	<0.01
35,000-60,000	686	11.5	713	11.6	674	11.3	2,602	14.3	
60,000-100,000	761	12.8	759	12.3	737	12.4	2,839	15.6	
More than 100,000	1,240	20.8	1,705	27.7	1,914	32.1	6,081	33.5	
Ever having a stressful episode									
Yes	1,919	30.9	1,851	28.8	1,583	25.6	6,821	28.2	<0.01
No	4,296	69.1	4,582	71.2	4,597	74.4	17,366	71.8	
Number of comorbidities									
0	4,226	68.0	1,725	26.8	1,371	22.2	8,907	49.0	
1-2	1,918	30.9	3,160	49.1	1,673	27.1	6,535	36.0	<0.01
More than 2	71	1.1	1,548	24.1	3,136	50.7	8,751	48.2	
Cognitive test (word recall)									
Less than 10	2,057	35.4	1,961	32.0	1,932	31.3	7,979	34.5	
10-15	3,444	59.3	3,670	59.9	3,727	60.3	13,540	58.5	<0.01
16-20	308	5.3	491	8.0	521	8.4	1,622	7.0	
Cognitive test (date recall)									
Less than 4	1,246	20.2	1,185	18.5	1,026	16.7	4,583	19.1	<0.01
4 (maximum)	4,919	79.8	5,224	81.5	5,117	83.3	19,427	80.9	

Note: Each column includes participants aged 50 to 99 and displays the descriptive statistics of each of the independent variables for all individuals included in the study sample (n=18,828 respondents) by wave. The full sample column includes all 24,187 individuals in the survey and the p-value represents the results of a bivariate test depicting the differences between the full sample and the study sample. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. 1 Great Britain Pound (GBP) is equivalent to approximately 1.4 USD. The education variable has eight categories from the National Vocational Qualification of England: no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate). Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis.

2.3.2 Outcome: allostatic load

The allostatic load metric measures the number of abnormal physiological biomarkers for chronic stress in the five dimensions described earlier. Most research studies in allostatic load classify an abnormal biomarker as that with a value above the 75th percentile of the empirical distribution of that indicator in the population, which provides a contextual appraisal of the abnormally high values of these biomarkers in the population under study.

In this study, the cut-off points to determine an abnormal biomarker are similarly set at the value corresponding to the 75th percentile of the distribution of the biomarker in the population stratified by sex. The reason to stratify the estimation of abnormal values for each biomarker by sex is intended to avoid penalizing one sex category when both men and women are assessed using the same thresholds. It is for this reason that we decided to stratify the thresholds, which are presented in table 2.2.

Table 2.2 Cut-off points for determining an abnormal biomarker

	Wave 2		Wave 4		Wave 6	
	Female	**Male**	**Female**	**Male**	**Female**	**Male**
Systolic blood pressure (mm Hg)	151.0	150.0	146.0	148.0	145.0	146.0
Diastolic blood pressure (mm Hg)	83.0	84.0	82.0	83.0	82.0	82.0
HbA1c (mmol/mol)*	5.7	5.8	6.0	6.0	42.0	43.0
BMI	31.1	30.2	31.4	30.5	31.4	30.6
Waist (cm)	98.5	108.5	100.8	109.4	100.2	109.2
Cholesterol (mmol/L)	6.9	6.3	6.6	6.0	6.6	6.0
C-Reactive Protein (mg/L)	3.5	2.9	4.3	3.6	3.5	2.9
Fibrinogen (g/L)	3.7	3.5	3.7	3.6	3.3	3.2

Note: The cut-off points are estimated at the value of the 75th percentile of the population distribution of each biomarker. *For waves 2 and 4, the measurement unit for HbA1c is percentage whereas for wave 6 is mmol/mol.

Similar to prior studies, in this research we assess the allostatic load using eight biomarkers available in the ELSA survey. Here, we list the biomarkers used in this study by dimension: 1) Cardiovascular activity, measured through the systolic and diastolic blood pressure. 2) Glucocorticoid activity is obtained by measuring the levels of total cholesterol, glycated hemoglobin, BMI and the waist diameter. 3) Finally, fibrinogen and the C-reactive protein is a proxy for inflammatory and immune activity. (Read and Grundy 2012).

Each abnormal biomarker adds up one unit towards the count of the allostatic load measured, which is scored between 0 and 8. In general, the literature on allostatic load presents heterogeneity in the number of actual biomarkers used across different studies. This is often caused by availability of datasets with those biomarkers; however, the findings in the literature on allostatic load have proven to be robust and consistent across slightly different indexes (Juster, McEwen, and Lupien 2010). This is likely due to the unidimensionality of the allostatic load measure (Howard and Sparks 2016). Given that some of the biomarkers used in estimating the allostatic load measure are also used for monitoring and diagnosing chronic conditions, an alternative allostatic load measure using two inflammatory biomarkers (fibrinogen and C-Protein Reactive) is included when assessing the relationship between comorbidities and allostatic load.

2.3.3 Independent variables

Wave was include as a control variable. All control variables are self-reported and classified into the following vectors:

2.3.3.1 Demographic variables

Sex: Allostatic load as well as the demand for prevention might differ by sex as shown in prior research (Seplaki et al. 2004).

Age: Allostatic load can vary over time in the same individual. To control for this fact, the variable age will be included in a linear form as most of literature uses it (Crimmins et al. 2003).

Government Office Region: This variable accounts for the nine administrative regions of England, which can be representative of differences on health outcomes and deprivation during childhood (Woods et al. 2005). Despite the fact that we do not have the location of the respondent during her childhood, this variable might be relevant because it provides a proxy for differences in the current environment related to geographical variation, which also affect chronic stress levels (Dahl 2004).

2.3.3.2 Socioeconomic variables

Marital status: This is an important variable because prior research shows evidence on the relationship of marital status with allostatic load levels and preventive behavior (Cramm and Nieboer 2012; Gersten, Dow, and Rosero-Bixby 2010). With the aim of simplifying the analysis, a dichotomous variable was built defining whether the individual lives with a partner (married, living with a permanent partner) or not (never married, widowed or divorced).

Belonging to a household with wealth higher than £35,000: Wealth was measured as a dichotomous variable signaling whether the household wealth where the respondent lives is located above or below the median of wealth estimated (£35,000). Similar to the work of Hamer

et al (Hamer, de Oliveira, and Demakakos 2014; Marmot et al. 2003), wealth was estimated as a monetized measure (in Great Britain Pounds) of the total household wealth net of household debt and excluding the participant's value of the home (with or without mortgage) and physical wealth such as artwork or jewelry. Different from what was done in Hamer et al study (Hamer and Stamatakis 2013), we included financial assets such as savings, and business assets for considering them an important part of the total wealth variable. Wealth is a more appropriate variable to measure the socioeconomic conditions of the respondent as seniors often count only partially on regular sources of income. Prior research has found there is a linear relationship of wealth with preventive behavior and allostatic load (Dowd and Goldman 2006; Evans and Schamberg 2009). Results in graphs were also shown comparing the top and lowest decile of the distribution of the wealth variable.

Education level: Education is found to be correlated with allostatic load in prior research studies (Kubzansky, Kawachi, and Sparrow 1999). In the population that pertains to this research, education is relatively exogenous as the educational choices were taken several decades before. This variable was included in its original format which is a variable with eight categories (no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate) equivalent to the National Vocational Qualification (NVQ1-5) official categorization of England (UK Government 2015).

Retirement: We included a binary variable accounting for whether the respondent reported to be retired at the time of the survey, as we anticipate this can be an important factor of stress. This is a dichotomous variable and does not account for different retirement statuses.

Size of the household: The size of the household is an important variable that is often used in research carried out in senior populations because it proxies the social capital and the family support of the respondent (Trujillo, Hyder, and Steinhardt 2011).

Having experienced a highly stressful episode: This variable has been used in the past as a proxy for stress in previous research (Costa and Kahn 2010). It can be a cause of chronic stress due to the trauma experienced early during the childhood, which previous research has shown is correlated with higher levels of allostatic load later in life (Turner, Thomas, and Brown 2016; Tomasdottir et al. 2015). This is a binary variable that accounts for whether any of the following events took place: 1) When aged under 16, parents who drank excessively, took drugs or had mental health problems; 2) Having had a husband, wife, partner or child who has been addicted to drugs or alcohol; 3) Ever being a victim of sexual assault (including rape or harassment); 4) Other than in war or military action, having ever witnessed an accident or violent act in which someone was killed or seriously wounded; 5) Having ever provided long-term care to a disabled or impaired relative or friend; and 6) Having ever experienced severe financial hardship.

2.3.3.3 Health and cognition variables

Number of comorbidities: Comorbidities are an important determinant of preventive behavior (Seplaki et al. 2005; S. L. Szanton et al. 2009). We included a variable accounting for the number of comorbidities that the individual has at each survey as this is a recognized proxy measure for the degree of comorbidity of the individual (Wolff, Starfield, and Anderson 2002). This measure includes the comorbidities that are deemed to produce the higher burden of disease in the United Kingdom (C. J. L. Murray and Lopez 2013): angina, myocardial infarction history, congestive failure, stroke history, lung disease or cancer. We also included the following comorbidities: high blood pressure, diabetes, high cholesterol, dementia, and arthritis. They were also included given its high prevalence and burden. These conditions were all self-reported and were summarized in a variable that summed up the number of these conditions present for each individual at each wave.

Difficulty walking 100 yards: This variable accounts for health issues that prevent the person to walk 100 yards and that would be expected to last more than 3 months. This constitutes a control variable for the level of disability experienced by the individual.

Cognitive skills: Allostatic load affects cognitive skills according to previous studies (Seplaki et al. 2005). As a consequence, cognitive and mental function was incorporated using two memory indices from the ELSA survey that have been used and validated in other population-level surveys (Ofstedal, Fisher, and Herzog 2005) for measuring one dimension of cognition. The first one is the date recall test, which is a 4-item variable accounting for recall of the current date (day, day of the week, month and year). The second one is the word recall test, which result is the sum of the number of words recalled immediately and after a delay (0 to 10 each for a total of 20).

2.4 Empirical strategy

Our empirical design is comprised by an ordinary least squares regression model that estimates the effect of the different independent variables described on the allostatic load measure[2]. The independent variables used are the following: age, sex, governmental office region, marital status, retirement status, whether the person belongs to a household with more than £35,000 of wealth,

[2] See appendix 2.1 for the results of the multiple regression of the different covariates on the full allostatic load variable and an alternative allostatic load variable using only two inflammatory biomarkers. From these regressions, we obtained the predicted values to create the graphs presented in this chapter.

level of education, size of the household, having experienced an stressful episode, number of comorbidities, difficulty to walk 100 yards, two cognition controls (date and number of words recalled) and wave. Survey weights are included in the regression analyses. The predicted values of that regression are then used to graph the predicted values against different variables.

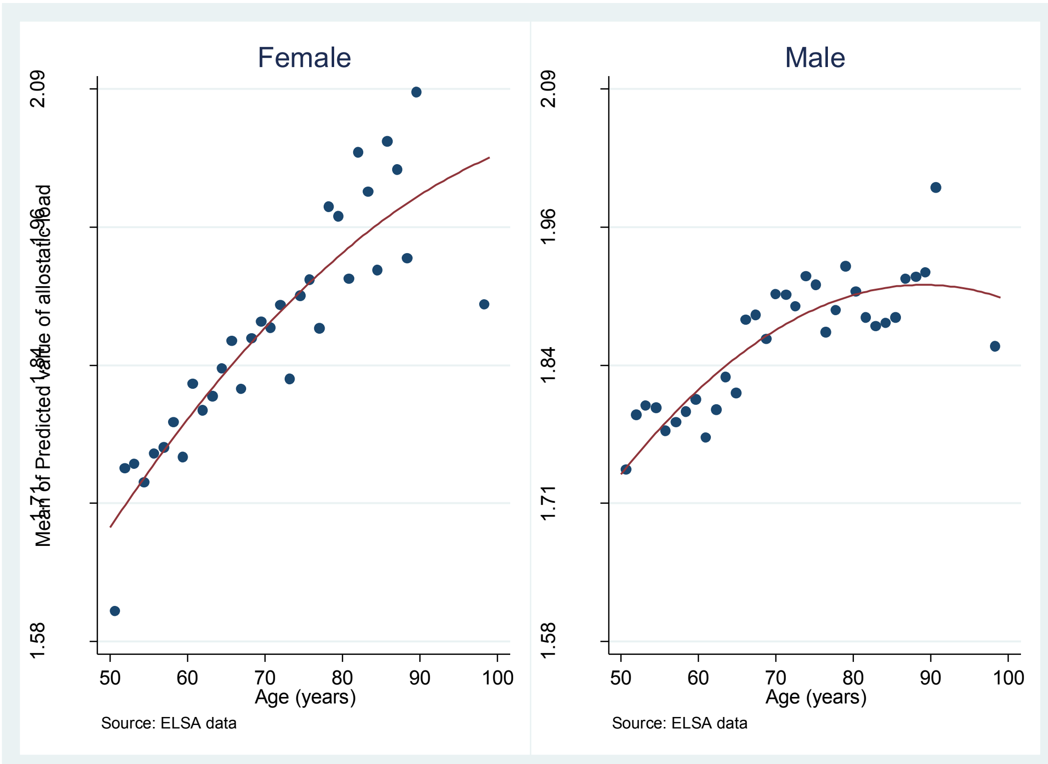
2.5 Results

2.5.1 Demographic factors and stress: Age and sex

We observe a steady increase in the average allostatic load measure with age. The average allostatic load at 50 years old is similar for men and women (Figure 2.1), and it increases at a similar average rate for women[3]. At around 75 years old, the allostatic load flattens out for men. This is likely a selection effect due to earlier mortality among men with higher allostatic load.

[3] See appendix 2.2 for unadjusted results of the effect of age on the allostatic load measure

Figure 2.1 Predicted values of the trajectory during the lifetime of the allostatic load metric by sex



Note: Predicted values for the allostatic load measure and age by sex. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

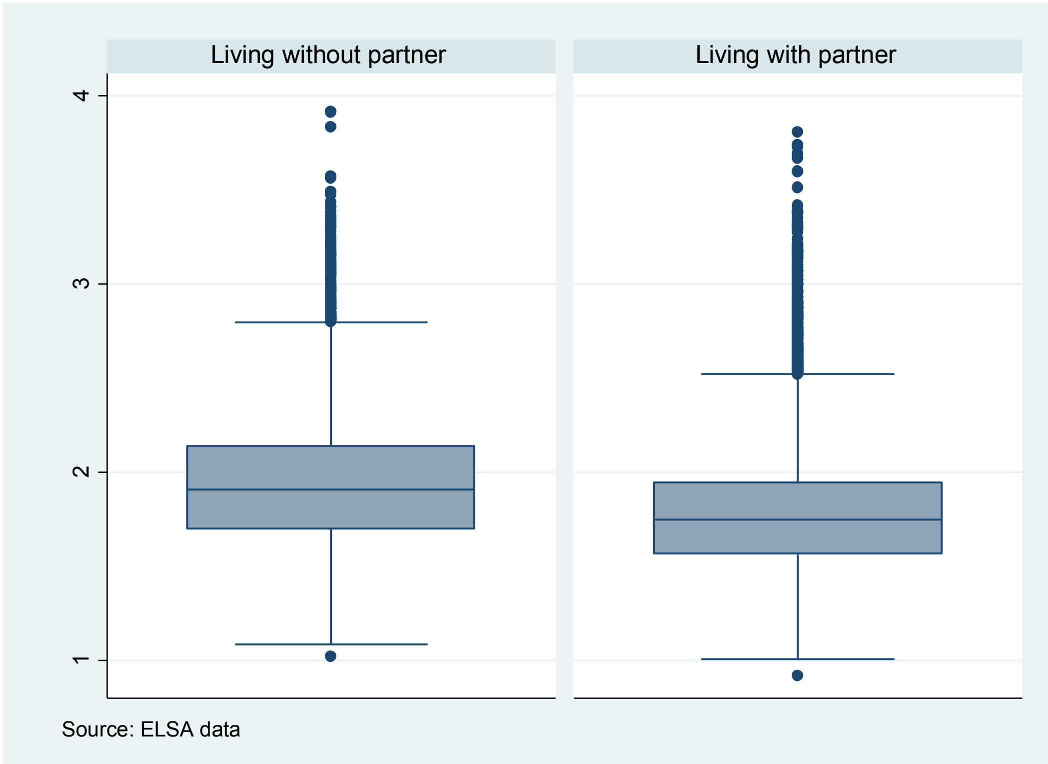
Increases in allostatic load with age are also consistent with prior research on chronic stress and allostatic load (Juster, McEwen, and Lupien 2010). Allostatic load is likely to be positively related with age as older individuals face an increasing financial vulnerability, changes in societal roles, decreasing cognitive skills, and higher incidence of disease, disability and widowing.

2.5.2 Social support on stress: marital status and household size

Marital status and household size represent variables that capture social support. Marital status is measured in this study as a binary variable defining whether the individual lives with a partner or not. In bivariate analyses, we found that people who do not live with a partner have an allostatic load metric that is 9% higher in average than those living with a partner[4,5]. In the adjusted results, we observe that living without a partner is related to a higher allostatic load, implying that this group of seniors find themselves under particularly higher stress (Figure 2.2.1, 2.2.2). In the elderly, the partner not only provides emotional support, but is also a source of financial and social support and increases the prospects of self-managing both chronic conditions and cognitive decline (Haslbeck, McCorkle, and Schaeffer 2012). Similarly, household size is a determinant of stress. Figure 2.3 shows the inverse relationship between the predicted value of the allostatic load and the household size. Prior research has shown that household size is related to a decreased suicide rate in the elderly (Shah 2009).

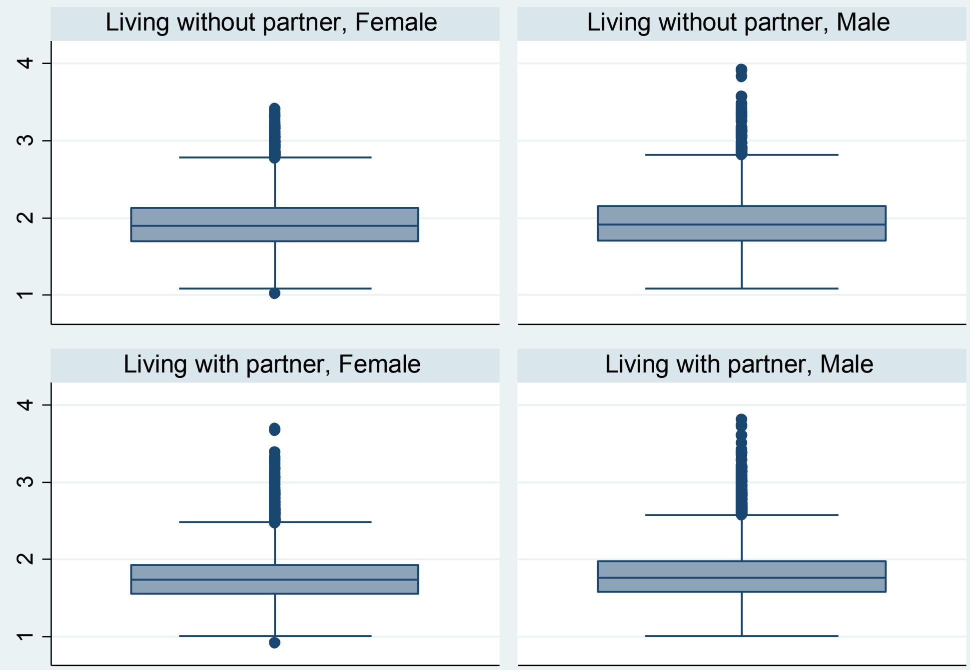
4 See appendix 2.3 for unadjusted results of the effect of living with a partner on the allostatic load measure
5 See appendix 2.4 for the average value of the allostatic load measure

Figure 2.2.1 Predicted values of the effect of the marital status on the allostatic load metric



Note: Predicted values for the allostatic load measure and marital status. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

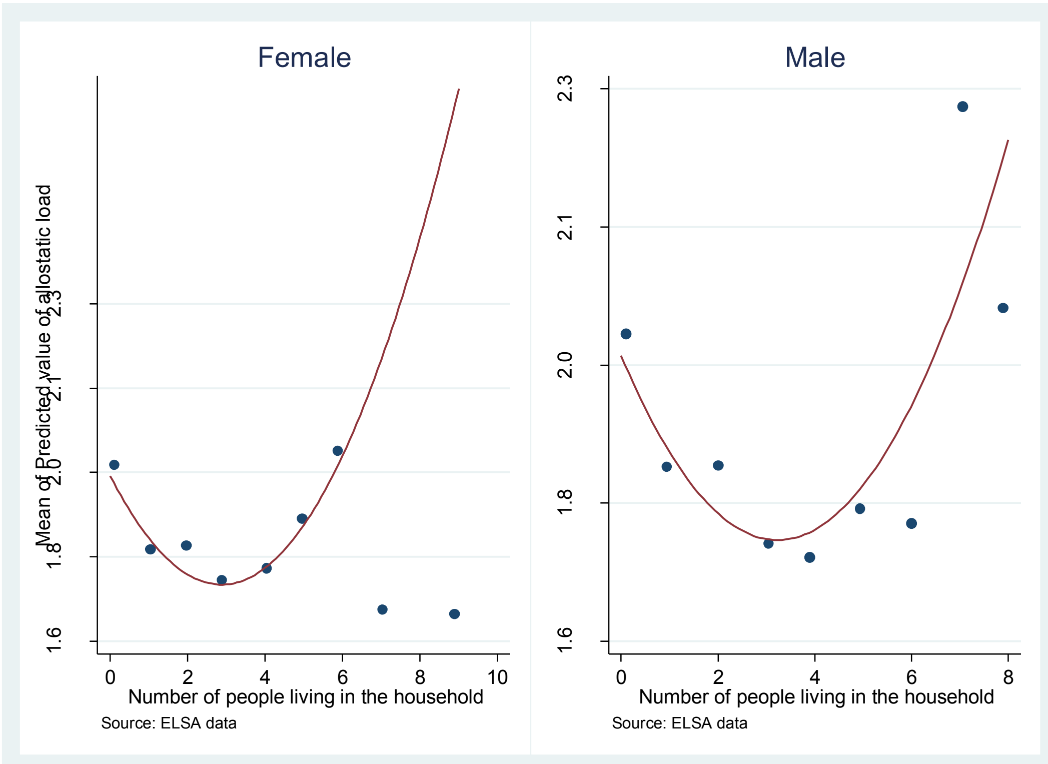
Figure 2.2.2 Predicted values of the effect of the marital status on the allostatic load metric by sex



Source: ELSA data

Note: Predicted values for the allostatic load measure and marital status by sex. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

Figure 2.3 Predicted values of the effect of household size on the allostatic load metric by sex.

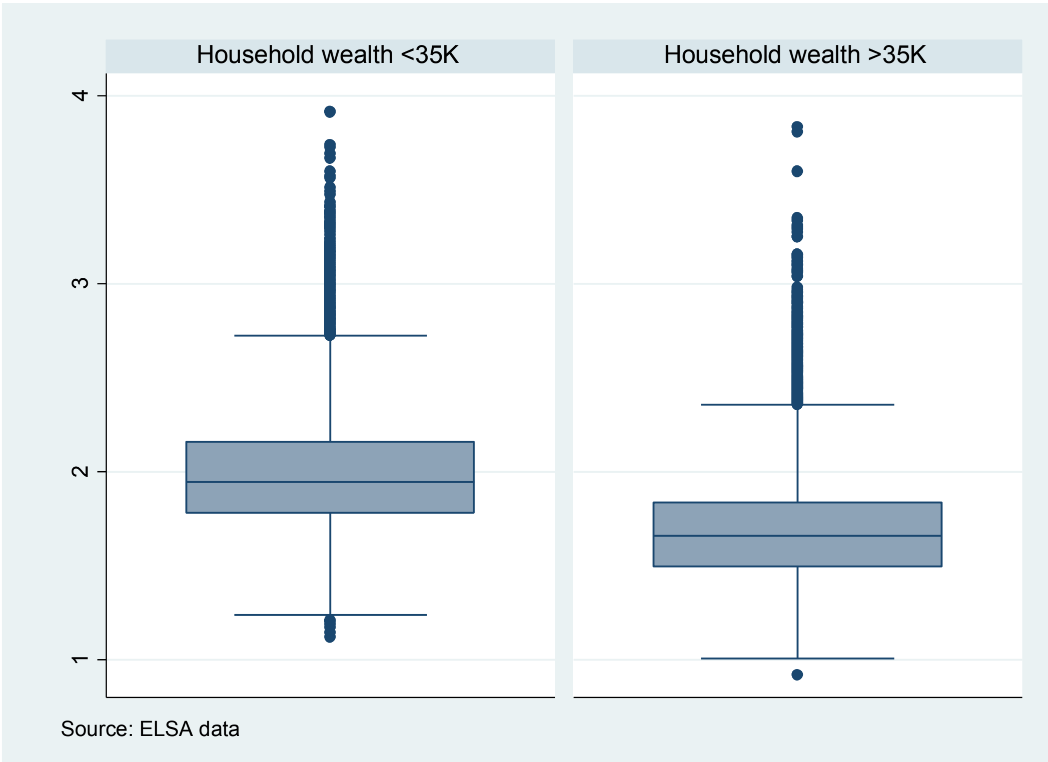


Note: Predicted values for the allostatic load measure and size of the household. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

2.5.3 Socioeconomic characteristics and stress: wealth

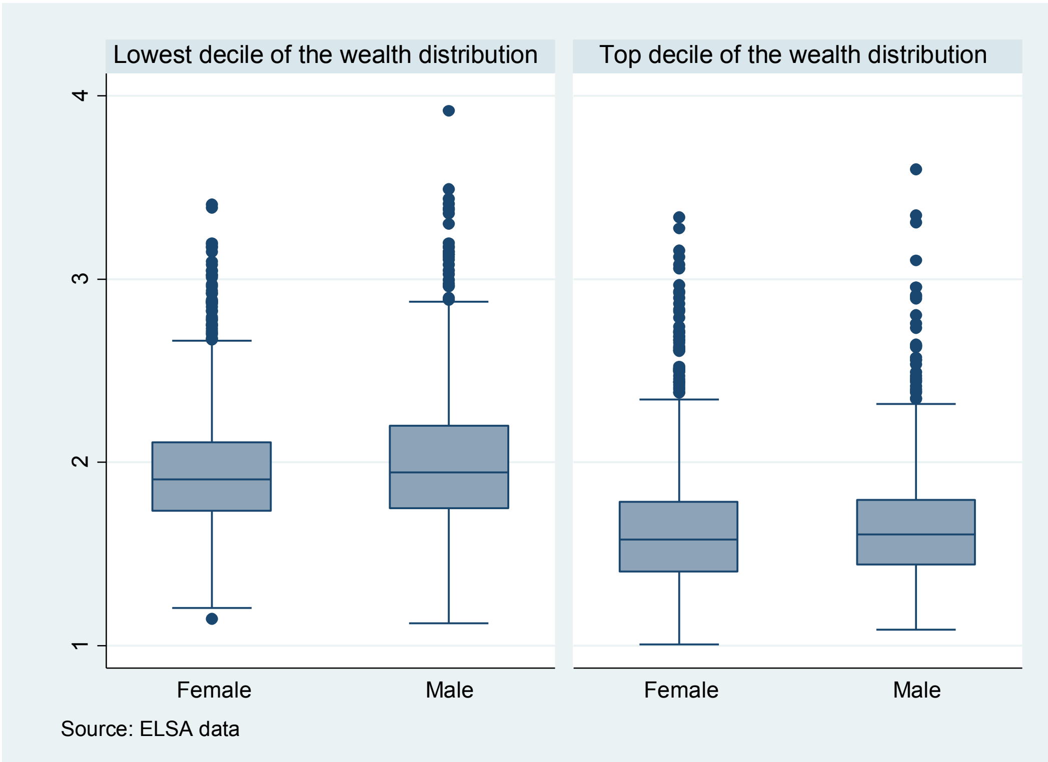
Socioeconomic conditions are a common source of chronic stress, especially among seniors (Dowd and Goldman 2006). Seniors often face a decreasing labor demand as they approach the retirement age leading to higher financial uncertainty (Office for National Statistics 2004). This increases their social and financial vulnerability, which can be a direct cause of stress. Our results show that respondents living in households with wealth more than £35,000 have an allostatic load measure in average 18% lower for both males and females (Figures 2.4.1and 2.4.2). Poverty has been long established as a factor determining chronic stress and higher levels of allostatic load. Higher levels of chronic stress in poor individuals are in part caused by the actual financial strain, but also from environmental factors related to poverty such as hostility (Kubzansky, Kawachi, and Sparrow 1999), and neighborhood conditions (Theall, Drury, and Shirtcliff 2012). Chronic stress resulting from these vulnerable socioeconomic conditions affects cognitive skills. Individuals who experienced poverty during adulthood seem to have lower levels of working memory, which is mediated by their higher levels of allostatic load (Evans and Schamberg 2009). More generally, the allostatic load measure has been shown to partially affect different cognition skills (Juster, McEwen, and Lupien 2010) when experiencing poverty (Mani et al. 2013). The cognitive effects of allostatic load among less affluent seniors are likely to perpetuate poverty in this population group as impaired decision-making processes can in turn, affect their ability to take appropriate financial decisions (Agarwal et al. 2007).

Figure 2.4.1 Predicted values of the allostatic load measure on the highest and lowest decile of the wealth distribution



Note: Predicted values for the allostatic load measure and belonging to either the top and lowest decile of the household wealth. The estimated difference using a t-test between both boxes is equal to 0.33 (SE: 0.011; $p<0.01$). N=3,557. Household wealth is net of debt and excludes mortgage and physical wealth such as property, artwork or jewelry. The threshold is defined at £35,000, the median of the estimated wealth in this study. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

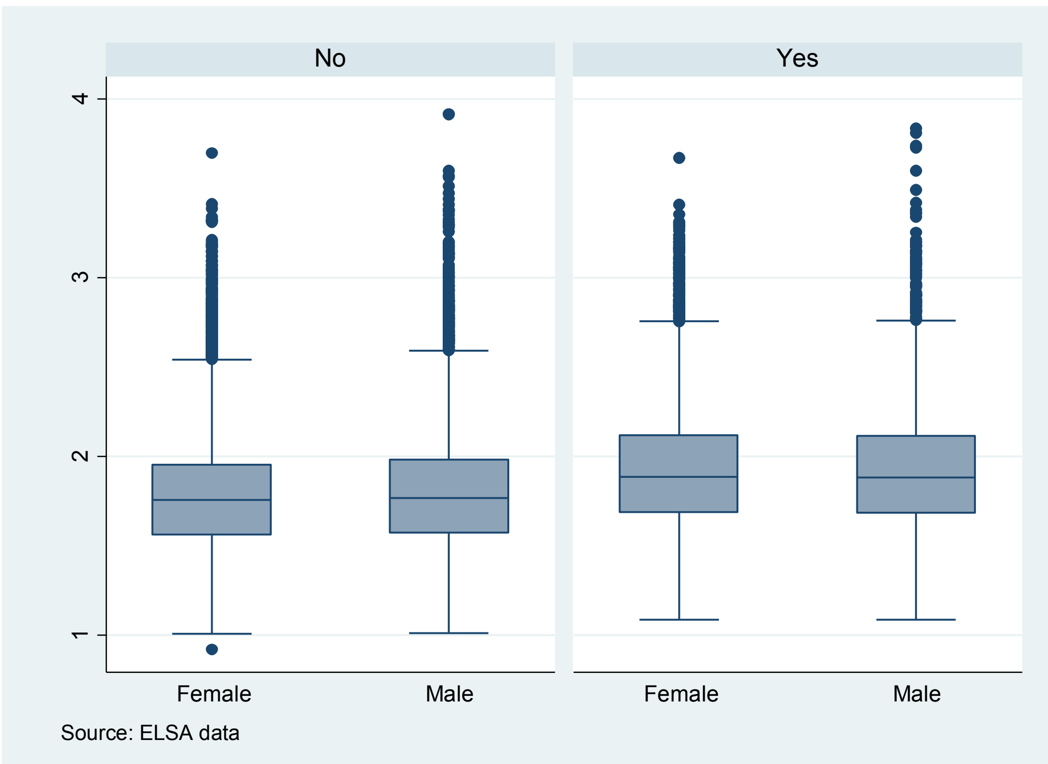
Figure 2.4.2 Predicted values of the allostatic load measure on the highest and lowest decile of the wealth distribution by sex



Note: Predicted values for the allostatic load measure and belonging to either the top and lowest decile of the household wealth by sex. Household wealth is net of debt and excludes mortgage and physical wealth such as property, artwork or jewelry. The threshold is defined at £35,000, the median of the estimated wealth in this study. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

We found that facing a significant stressful episode during the life is positively correlated to the allostatic load measure. This is an expected result since facing stressful episodes in life either in early and late life have been associated to higher levels of allostatic load (Turner, Thomas, and Brown 2016; Tomasdottir et al. 2015; Woods et al. 2005).

Figure 2.5 Predicted values of the allostatic load measure and reporting having experienced any stressful event by sex



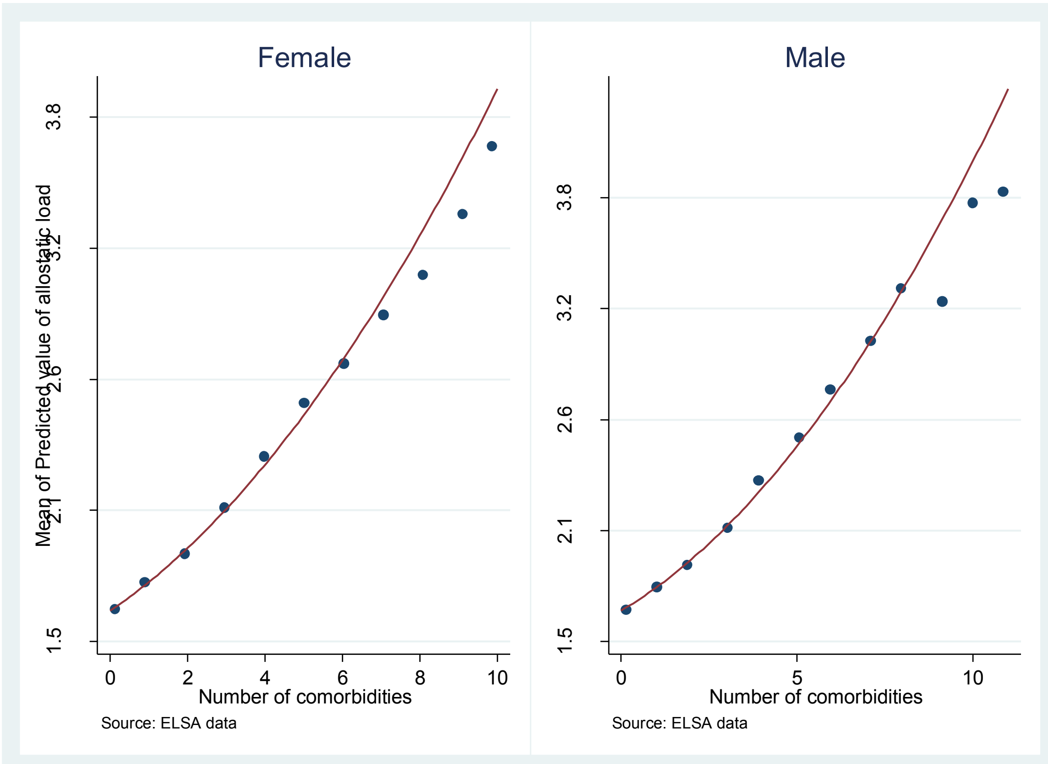
Note: Predicted values for the allostatic load measure and reporting having experienced at least one stressful episode during the lifetime by sex. Linear combination shows a difference in the average allostatic load measure between those having and not having experienced a stressful event of 0.14; SE: 0.025; $p<0.01$. A stressful episode is defined as: 1) When aged under 16, parents who drank excessively, took drugs or had mental health problems; 2) Having had a husband, wife, partner or child who has been addicted to drugs or alcohol; 3) Ever being a victim of sexual assault (including rape or harassment); 4) Other than in war or military action, having ever witnessed an accident or violent act in which someone was killed or seriously wounded; 5) Having ever provided long-term care to a disabled or impaired relative or friend; and 6) Having ever experienced severe financial hardship. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

2.5.4 Health and stress: chronic conditions and cognition

Chronic conditions will represent 75% of the deaths worldwide by 2020, and the United Kingdom has shown below-average performance in terms of health outcomes and incidence of chronic conditions when compared to other European countries (C. J. Murray et al. 2013). Chronic conditions have been documented as sources of stress among seniors (Rebok, Parisi, and Kueider 2014) as they increase their level of emotional, social and financial vulnerability and lead to frailty and disability. We found that a higher number of comorbidities is related to higher levels of allostatic load (Figure 2.6). Because, some of the biomarkers used to measure allostatic load are also biomarkers present in the case of chronic conditions, we repeated the same analysis using only inflammatory biomarkers (fibrinogen and C-Reactive Protein) that do not constitute directly biomarkers used to diagnose chronic conditions (Figure 2.7). This two biomarkers have been used in previous research(Stringhini et al. 2016). We found that an additional comorbidity increases the allostatic load around 10% when measuring it with the full allostatic load metric and in around 13% when using the alternative allostatic load metric that only accounts for the two inflammatory biomarkers[6]. These results need to be carefully assessed. There is a clear correlation between the diagnosis of chronic conditions and some of the biomarkers used in the allostatic load measure. However, the allostatic load metric is the best resource available to measure chronic stress using physiological biomarkers, and it is for this reason that this type of sensitivity analyses is always warranted.

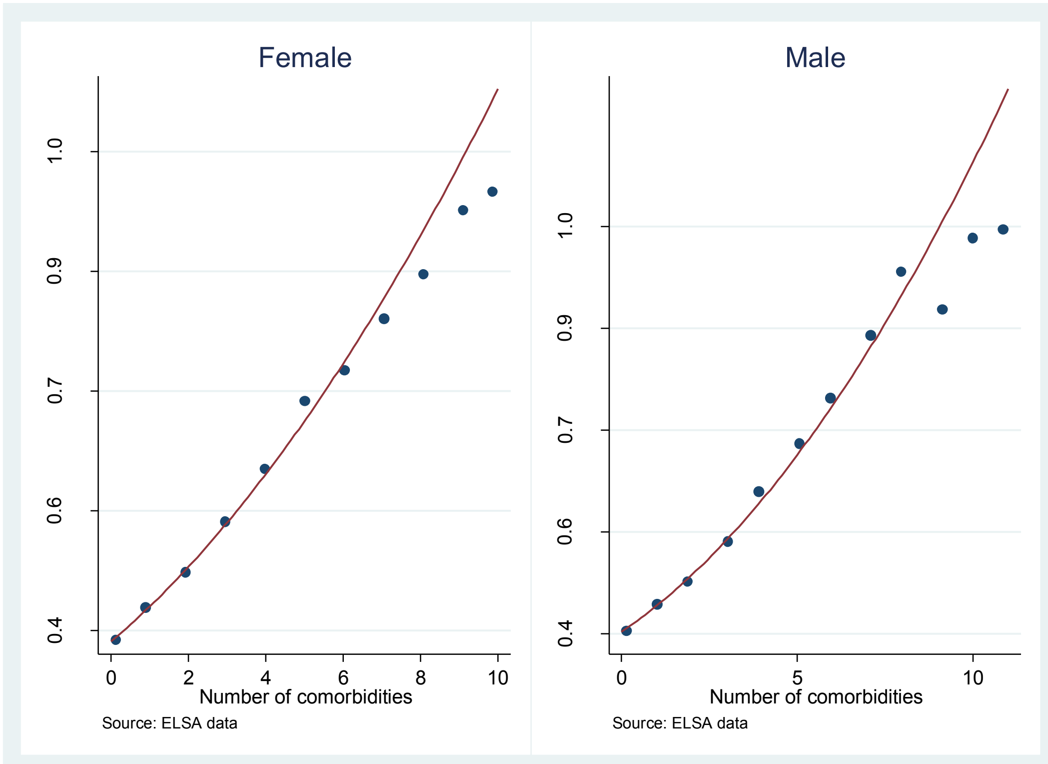
[6] See appendix 2.3 for unadjusted results.

Figure 2.6 Predicted values of the effect of number of comorbidities on the allostatic load metric by sex.



Note: Predicted values for the allostatic load measure and number of comorbidities. Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, dementia congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

Figure 2.7 Predicted values of the effect of number of comorbidities on the allostatic load metric (only with inflammatory biomarkers) by sex.



Note: Predicted values for the allostatic load measure (with only inflammatory biomarkers, fibrinogen and C-reactive protein) and number of comorbidities. Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, dementia, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

In table 2.3, we display the average levels of allostatic load by type of comorbidity. Among those who had any comorbidity, we found that reporting heart failure is consistently associated with the highest levels of allostatic load. Individuals with higher levels of cholesterol are associated with the lowest levels. Diabetes ranks higher when measured with the full allostatic load metric than when it is used with the inflammatory biomarkers. This is probably because diabetes itself can increase the levels of the biomarkers used to calculate the allostatic load metric.

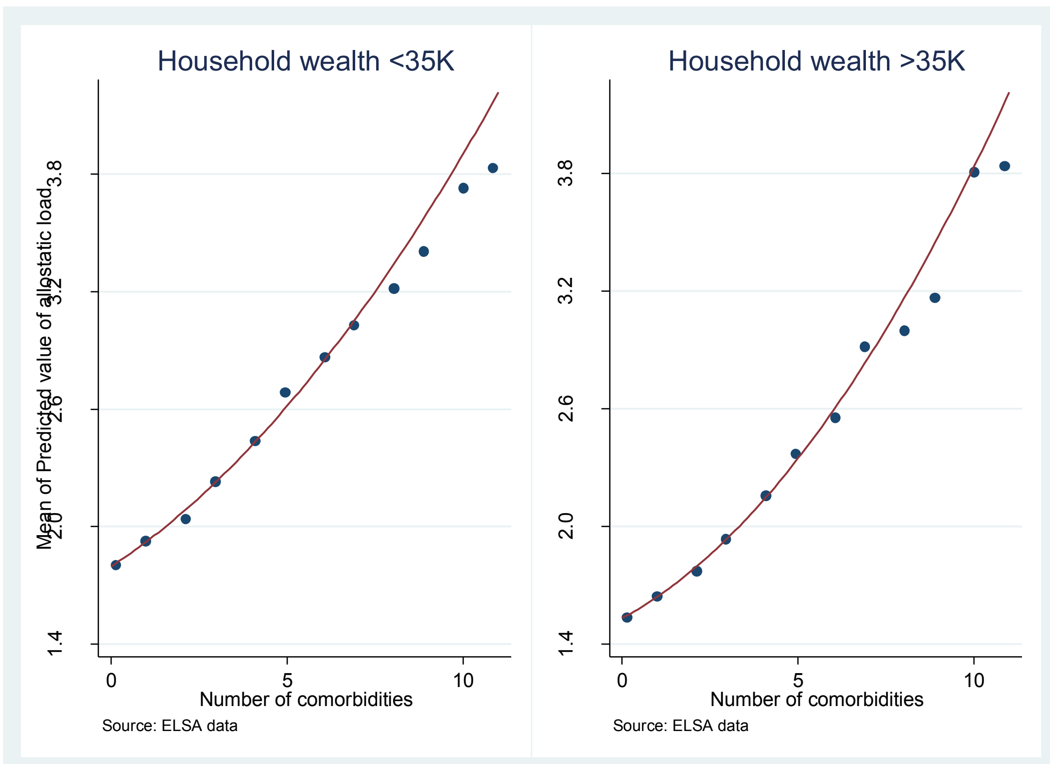
Table 2.3 Average allostatic load, and average allostatic load measured only with inflammatory biomarkers by chronic condition

Chronic condition	n	Allostatic load		Allostatic load (only inflammatory biomarkers)	
		Mean	Standard error	Mean	Standard error
No comorbidity	7,322	1.55	0.02	0.38	0.01
Angina	864	1.98	0.05	0.53	0.03
Myocardial infarction	719	2.04	0.06	0.62	0.03
Cancer	774	1.96	0.06	0.54	0.03
Heart failure	38	2.74	0.28	0.79	0.13
Stroke	483	1.99	0.07	0.61	0.04
Lung disease	859	2.22	0.06	0.77	0.03
Hypertension	5,614	2.26	0.02	0.55	0.01
Diabetes	1,271	2.72	0.04	0.58	0.02
Cholesterol	4,574	2.00	0.02	0.49	0.01
Arthritis	5,628	2.09	0.02	0.54	0.01

Note: Each column includes participants aged 55 to 99 with each of the comorbidities listed. 18,826 individuals with allostatic load measurement are listed in all the corresponding rows. The first column (allostatic load) represents the allostatic load metric measured with the eight biomarkers. The second column represents the sum of only the two inflammatory biomarkers (fibrinogen and C-reactive protein). Taylor linearized standard errors displayed.

In figure 2.8, we show that when the relationship between allostatic load and number of comorbidities is stratified by level of wealth, individuals living in households with levels of wealth lower than £35,000 have higher levels of allostatic load for any given number of comorbidities.

Figure 2.8 Predicted values of the effect of number of comorbidities on the allostatic load metric by category of household wealth.



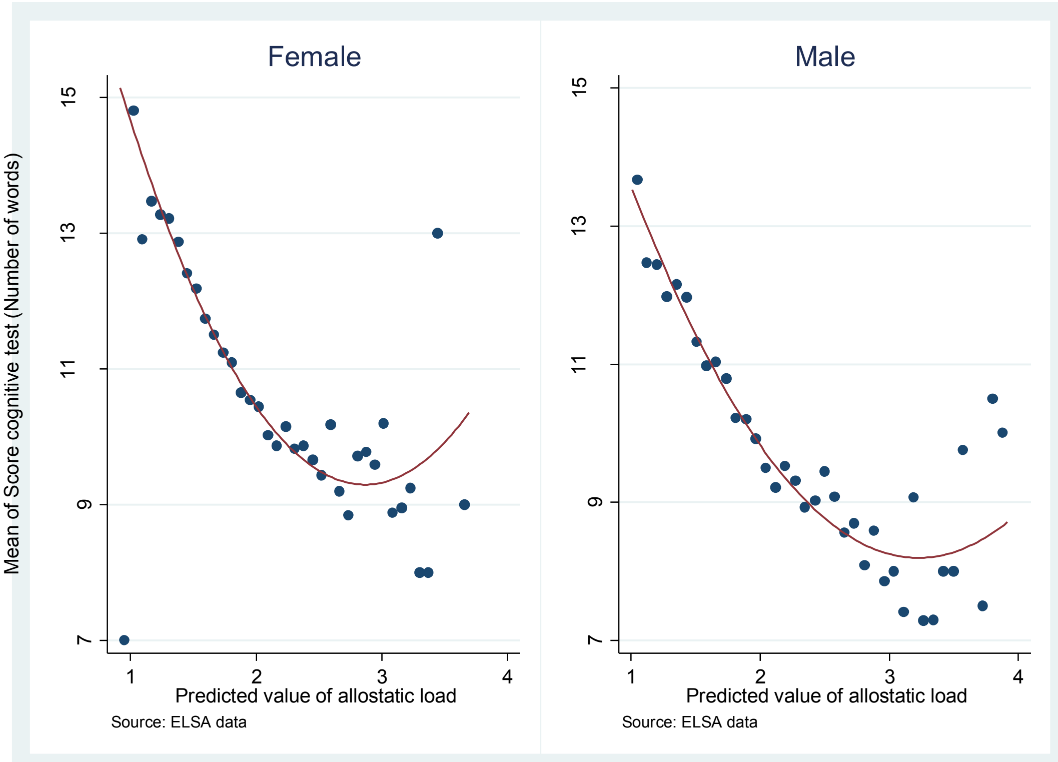
Note: Predicted values for the allostatic load measure and number of comorbidities by category of household wealth. Household wealth is net of debt and excludes mortgage and physical wealth such as property, artwork or jewelry. The threshold is defined at £35,000, the median of the estimated wealth in this study. Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, dementia, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

Decreasing cognitive skills is also related to increases allostatic load. In our study, an increase in one unit of the allostatic load measure leads to a reduction in the average score of the word recall test of 0.16 for women and 0.12 for men. Similar increases are related to a reduction of 0.01 in the date recall test (figure 2.8 and 2.9)[7]. The impact of an increase in one unit in the allostatic load in the word recall test is equivalent to losing around 40% of the benefit obtained from a classroom-based mnemonic training (Kueider et al. 2012; Flnkel and Yesavage 1989).

The reduction in cognitive skills related to the increase in allostatic load is important. Prior research has shown that increases in allostatic load can affect cognitive functions such as working memory (Diamond 2005; Evans and Schamberg 2009), positive responses to the environment (Lindfors, Lundberg, and Lundberg 2006) and functionality (Kado et al. 2005; Karlamangla et al. 2002; Seplaki et al. 2004). This implies that stress might affect temporal consistency and reduce the capacity to act (Aken & van Aken, 1991), depleting self-control and inducing myopic responses in the individuals (Diamond 2005; Evans and Schamberg 2009; Glanz, Rimer, and Viswanath 2008; Karlamangla et al. 2005; Lindfors, Lundberg, and Lundberg 2006; Muraven and Baumeister 2000; T. E. Seeman, McEwen, et al. 1997). This dissertation will show in its fourth chapter that increases in allostatic load are related to a reduction in preventive behavior such as tobacco consumption and breast cancer screening[8], which we hypothesize as a potential consequence of the reduction in cognitive skills from increases in the allostatic load measure.

[7] See appendix 2.5 for unadjusted results.
[8] This comprises the aim 3 of this dissertation

Figure 2.9 Predicted values of the effect of the allostatic load measure on the cognitive test (number of words recalled) by sex.



Note: Score of the cognitive test for number of words recalled and predicted values for the allostatic load measure. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

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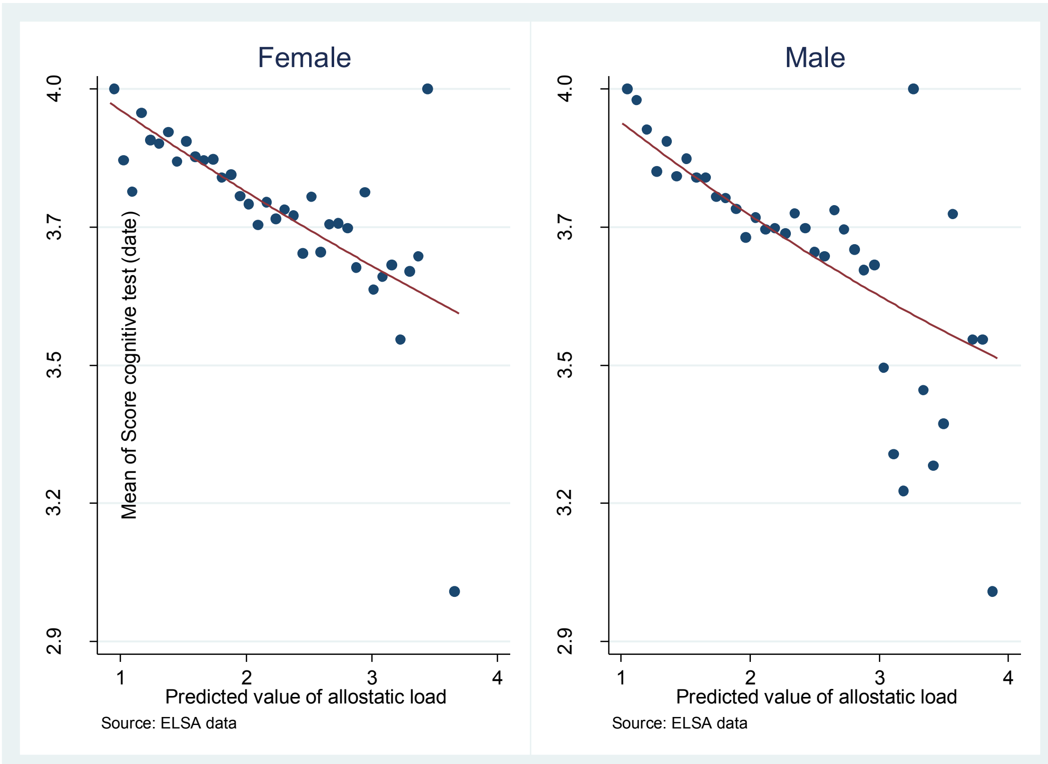
Figure 2.10 Predicted values of the effect of the allostatic load measure on the cognitive test (Date recalled) by sex.



Note: Predicted values for the allostatic load measure and the score of the cognitive test for recalling the date. Predicted values are a result of the regression of the allostatic load measure on age, governmental office region, marital status, retirement status, total household wealth, level of education, size of the household, having experienced a stressful episode, number of comorbidities, wave, difficulty to walk 100 yards, and two cognition controls (date and number of words). 17,279 respondents, 9,514 women and 7,765 men included in the graph. Survey weights are included.

2.6 Discussion

Using data from the ELSA survey and taking advantage of the allostatic load metric we showed how the allostatic load metric, as a proxy for chronic stress, correlates with different demographic, socioeconomic and health characteristics in the population of seniors in England. Importantly, allostatic load increases with age; it seems to be affected by the social support net, including the number of people living in the household, and by whether the person is living with a partner. We also observed that the allostatic load is higher among individuals with lower household wealth, more comorbidities, those who report having highly stressful experiences, and individuals with lower scores on the cognitive tests.

We showed that the relationship between the predicted value of allostatic load and household size is negative[9]. Prior research has shown that household size is related to a decreased suicide rate in the elderly (Shah 2009). This study argues that seniors living with more people have more social support and are less likely to be alone.

Our results provide evidence that the higher levels of allostatic load among seniors in England are found in the more vulnerable ones, which is consistent with prior studies conducted in other countries (Kubzansky, Kawachi, and Sparrow 1999). This has important public policy implications. First, the higher levels of stress in these groups imply that despite the various programs that target seniors in England (Wacker and Roberto 2011), differences in allostatic load are associated to differences in wealth. These differences are reflected as a higher burden of

9 Also see appendix 2.2

allostatic load for seniors in more vulnerable conditions. These results show that the burden of stress unequally affects seniors across levels of wealth.

The impact of changes in the allostatic load can be hard to grasp since it is not a widely used metric yet. However, prior studies might shed a light on the significance of these findings. Prior research has found that the differences in allostatic load levels in the United States between white and African Americans reach in average 0.45 (Geronimus et al. 2006) and 0.12 between white and US born citizens of Mexican origin (Peek et al. 2010). The differences shown in figure 2.4.1 are equal to a difference of 0.33 (See note in the graph). This implies that the differences in stress levels between English seniors living in the top and lowest decile of the wealth distribution are equivalent to 60% of the differences between white and African American in the US and more than three times the differences between white and US born citizens of Mexican origin.

More broadly, while aspects such as comorbidities and reduced cognition are almost inevitably linked to higher levels of allostatic load and chronic stress, the fact that seniors living in less affluent households have a higher level of allostatic load implies that living in poverty conditions might be related to higher levels of wear and tear in the body. This, by itself constitutes an additional dimension of the extent to which poverty has an impact in everyday lives, with potential costs in terms of mortality, health and social care (Juster, McEwen, and Lupien 2010).

This paper discusses how systematic differences in chronic stress among more vulnerable individuals, such as on those living without a partner, living alone and living in poverty can constitute a perpetuating cycle that needs to be properly addressed by policy-makers, especially for seniors that belong to the more vulnerable groups of the society. Higher levels of chronic stress have shown to be related to higher prevalence of disease (Bruce S. McEwen 2004), to reduce the ability to successfully manage and cope with stressful situations (Aken & van Aken, 1991), and to perform preventive care (See chapter 4 of this dissertation)[10]. Increases in chronic stress levels are not trivial. Prior research has shown that higher levels of stress are associated with all-cause mortality (Goldman et al. 2006), constituting a potential burden for health care and social systems.

This paper contributes to the growing body of research providing population-level insights of how social factors are related to the allostatic load measure. Chronic stress has been traditionally investigated from a purely individual perspective despite prior literature showing a consistent relationship of chronic stress with demographic, socioeconomic, and health conditions, (Bruce et al. 2013; Catalano 2009; Chrousos GP and Gold PW 1992; Goh, Pfeffer, and Zenios 2015; Rosengren et al. 1993; Juster, McEwen, and Lupien 2010). This study attempts to approach the issue of chronic stress from a syndemic perspective, understanding that chronic stress is not an isolated individual circumstance, but it is just the individual consequence of a more complex system of factors that require a broader societal perspective (Singer 2009).

The improvements on measurement in biomarkers of population-level surveys over the last years have allowed us to understand the determinants of chronic stress, and to build this knowledge base. Future research should address the mechanisms by which these improvements in measuring can be reflected in actual policy options to improve population well-being. Social systems are dynamic in nature and they can take advantage of the opportunities offered by technological change in order to improve the marginal social productivity of programs aimed at improving society's well-being. We believe that the increasing use of biomarkers for the measurement of chronic stress might

[10] The fourth chapter of this dissertation discusses the effect of the allostatic load on preventive behavior.

represent a phase transition in the way that social services are delivered by both improving the targeting of vulnerable individuals and the understanding of the underlying mechanisms of the interrelations between social phenomena and disease (Paina and Peters 2011). This study contributes to the literature supporting such phase transition towards stronger social and health systems that can take advantage of biomarker data. One concrete example is represented in the next chapter of this dissertation[11] where we attempt to provide an insight as to how a social program can have a measureable impact on the levels of allostatic load.

It is important to notice that, as shown in table 2.2, the data used in this study comprises a subsample of healthier seniors as we are relying on respondents who had biomarker samples taken. This possibly implies that our results underestimate the magnitude of the relationships found and that they are likely to be higher when observing less healthy individuals. The results shown here comprise relationships that are not causal and that are susceptible to endogeneity and reverse causality issues.

These results are consistent with research found in other middle and high-income countries and provide information on the characteristics of seniors with higher levels of allostatic load. Further research focusing on potential social programs that can affect stress at a population- rather than at an individual level are needed. Evidence confirming the external validity of these results in other countries and populations is essential to advance our knowledge on stress and how it affects population health.

[11] Chapter 3 comprises the aim 2 of this dissertation and assess the effect of the state pension in England on the allostatic level measure.

Appendix 2.1

Multivariate regression on different characteristics on allostatic load

	Allostatic load			**Allostatic load (inflammatory biomarkers)**		
	Coeff	**Standard error**	***p***	**Coeff**	**Standard error**	***p***
Age	-0.01	0.00	<0.01	0.00	0.00	0.38
Sex (REF: Female)	0.10	0.03	<0.01	0.04	0.01	<0.01
Region						
North-East	Ref	Ref	Ref	Ref	Ref	Ref
North-West	0.02	0.06	0.66	-0.04	0.03	0.12
Yorkshire and the Humber	0.08	0.06	0.17	-0.01	0.03	0.60
East Midlands	0.07	0.06	0.23	0.01	0.03	0.81
West Midlands	0.07	0.06	0.23	-0.02	0.03	0.47
East of England	0.03	0.06	0.61	-0.02	0.03	0.55
London	0.00	0.06	0.99	0.00	0.03	0.97
South-East	0.00	0.05	0.96	-0.03	0.02	0.25
South-West	0.08	0.06	0.13	-0.01	0.03	0.83
Marital Status (REF: Living without a partner)	-0.06	0.03	0.04	-0.03	0.01	0.05
Retired	0.07	0.03	0.02	0.04	0.01	<0.01
Belonging to a household with more than 35,000	-0.15	0.03	<0.01	-0.06	0.01	<0.01

Note: Results of the multivariate regression of each of the characteristics on the allostatic load measure. It includes participants aged 50 to 99. The first set of columns comprises the results of the regression using the allostatic load measure F=35.02; R-squared =0.0526; N=17,279. The second of columns comprises the results of the regression using the allostatic load measure with only two inflammatory biomarkers F=26.72; R-squared =0.0423; N=17,279

Appendix 2.1 (cont.)

Multivariate regression on different characteristics on allostatic load (cont.)

	Allostatic load			Allostatic load (inflammatory biomarkers)		
	Coeff	**Standard error**	***p***	**Coeff**	**Standard error**	***p***
Education						
Foreign	0.12	0.06	0.06	0.05	0.03	0.07
No qualification/other	Ref	Ref	Ref	Ref	Ref	Ref
NVQ1	-0.02	0.07	0.81	0.01	0.03	0.76
NVQ2	-0.05	0.06	0.41	-0.01	0.03	0.70
NVQ3	-0.09	0.07	0.21	-0.02	0.03	0.46
NVQ4	-0.13	0.07	0.05	-0.05	0.03	0.09
NVQ5	-0.33	0.06	<0.01	-0.11	0.03	<0.01
Size of the household	-0.01	0.02	0.46	-0.01	0.01	0.08
Experiencing stressful episodes	0.10	0.03	<0.01	0.03	0.00	<0.01
Number of comorbidities	0.16	0.01	<0.01	-0.01	0.01	0.36
Cognitive test (Word recall)	-0.01	0.03	0.73	0.00	0.00	0.05
Cognitive test (date recall)	-0.01	0.00	0.14	0.25	0.03	<0.01
Difficulty walking 100 yards	0.48	0.05	<0.01	-0.03	0.01	0.02
Wave 2	Ref	Ref	Ref	Ref	Ref	Ref
Wave 4	-0.18	0.03	<0.01	-0.04	0.01	<0.01
Wave 6	-0.20	0.03	<0.01	0.50	0.09	<0.01
Constant	2.56	0.18	<0.01	0.50	0.09	<0.01

Note: Results of the multivariate regression of each of the characteristics on the allostatic load measure. It includes participants aged 50 to 99. The first set of columns comprises the results of the regression using the allostatic load measure F=35.02; R-squared =0.0526; N=17,279. The second of columns comprises the results of the regression using the allostatic load measure with only two inflammatory biomarkers F=26.72; R-squared =0.0423; N=17,279

Appendix 2.2

Bivariate regression on different characteristics on allostatic load by sex

Allostatic load	Female (n=10,319)			Male (n=8,509)		
	Mean	Standard error	*p*	Mean	Standard error	*p*
Age	0.01	0.00	<0.01	0.00	0.00	0.65
Size of the household						
Size of the household	-0.07	0.02	<0.01	-0.06	0.02	<0.01
Size of the household squared	-0.01	0.01	0.24	-0.01	0.00	0.06
Belonging to a household with more than 35,000	-0.35	0.03	<0.01	-0.27	0.03	<0.01
Number of comorbidities	0.18	0.01	<0.01	0.16	0.01	<0.01
Number of comorbidities (using inflammatory biomarkers)*	0.06	0.00	<0.01	0.05	0.01	<0.01
Cognitive test (word recall)	-0.04	0.00	<0.01	-0.03	0.01	<0.01
Cognitive test (date recall)	-0.07	0.04	0.05	-0.12	0.03	<0.01

Note: Results of the bivariate regression of each of the characteristics on the allostatic load measure. Each column includes participants aged 50 to 99. * The variable number of comorbidities in this row was estimated using only the inflammatory biomarkers (C-reactive protein and fibrinogen) to confirm that the number of comorbidities remain a significant factor when no direct biomarkers for diagnosis or monitoring chronic conditions are used

Appendix 2.3

Means test of the effect of marital status on the allostatic load metric.

Allostatic load	**Mean**	**Standard error**	**Linear combination**	**Standard error**	***p***
Living without partner	1.95	0.02	0.17	0.02	<0.01
Living with partner	1.78	0.01			

Note: Means test on the effect of the allostatic load measure on marital status. 18,821 participants aged 50 to 99 included.

Appendix 2.4

Differences on the full allostatic load measure and the allostatic load measure using only inflammatory biomarkers by sex

Allostatic load	Female (n=10,319)		Male (n=8,509)		*p*
	Mean	Standard error	Mean	Standard error	
Full allostatic load metric	1.83	0.02	1.84	0.02	0.49
Allostatic load metric using only inflammatory biomarkers	0.45	0.01	0.46	0.01	0.39

Note: Bivariate regression analyses on the allostatic load measure by sex. 18,828 participants aged 50 to 99 included. *The first row (full allostatic load) represents the allostatic load metric measured with the eight biomarkers. The second row represents the sum of only the two inflammatory biomarkers (fibrinogen and C-reactive protein).

Appendix 2.5

Effect of the allostatic load on cognitive scores by sex

Allostatic load	Female (n=7,561)		*p*	Male (n=6,046)		*p*
	Mean	Standard error		Mean	Standard error	
Cognitive test (Word recall)	-0.16	0.02	<0.01	-0.12	0.02	<0.01
Cognitive test (date recall)	-0.01	0.00	0.05	-0.01	0.00	<0.01

Note: Results of the bivariate regression of each of the allostatic load measure on each of the cognitive tests. Each column include participants aged 50 to 99.

3. Do pension programs reduce chronic stress levels among seniors in England?

Abstract

We study the effect of the state pension program in England on chronic stress, as measured by the allostatic load measure. By providing financial relief, pension programs reduce the levels of stress of their beneficiaries implying that these programs might generate previously unmeasured welfare gains in terms of stress reductions. This study provides evidence that suggests that becoming eligible for the UK state pension reduces the levels of allostatic load (our measure of chronic stress) by between 11% to 17% (depending on the specification) among males living in less wealthy households with no significant impact on respondents living in the wealthier ones. We also found that the state pension reduces the allostatic load levels among women who both live in less wealthy households and who live by themselves. Our findings are robust to several alternative specifications including higher-order polynomials and the inclusion of retirement. We provide policy recommendations based on these results.

3.1 Introduction

Pension programs are aimed at improving the society's welfare and protecting vulnerable populations. Without the existence of financial protection schemes, senior citizens become financially vulnerable as their capacity to perform work diminishes, reducing their income (Anderson and Hussey 2000) to the point in which many will approach poverty levels (Price 2006). For this reason, the United Kingdom (UK), first based on the 1908 Old Age Pensions Act, and as a result of the Beveridge report in 1942, created the basic state pension with the aim of reducing the risk of the elderly of falling below the poverty line. (Institute for Fiscal Studies 2010). The state pension is a contributory system where individuals make National Insurance Contributions (NIC) during their lifetimes and receive a price-indexed basic state pension when they reach the eligibility age. In addition to this basic state pension, the State Second Pension scheme (S2P) was introduced in 2002, replacing the prior State Earnings-Related Pension introduced in 1978. The S2P is a voluntary scheme that indexes the pension on the amount of their own personal contributions. The UK state pension has undergone multiple revisions because it demands a significant level of public resources (Institute for Fiscal Studies 2010; MacKellar et al. 2001). There are around 12 million seniors living in England above the state pension eligibility age (Rutherford 2012). In 2012, the UK state pension represented £94 billion, equivalent to 6% of the UK GDP per year (Office for National Statistics 2016).

Pension programs are common in most middle and high-income countries. Even though their financial structure changes depending on the country and the regimen (public and private), common aspects to pension schemes are that these are contribution-based systems that provide income support, and therefore smooth the consumption path as eligible seniors approach retirement. However, pension programs also provide seniors with non-pecuniary gains that have economic value. Pension programs reduce financial uncertainty and keep financial independence.

Most of pension programs are facing increasing financial challenges as seniors become a larger proportion of the population and life expectancy is increased. Consequently, governments see themselves in the unpopular position of modifying pension schemes by modifying the amounts provided or their eligibility criteria. For these reasons, governments need to balance the costs and benefits of these programs to maximize the tradeoff between the wellbeing of seniors and the sustainability of public finances.

The state pension is a government program that includes all men older than age 65 and all women between 60 and 62 years old, depending on their year of birth[12]. To become eligible the individual needs to reach the eligibility age and have contributed to National Insurance payments for at least 10 years (NIDirect 2010; UK Government 2016c). The state pension provides up to £115.95 per week to eligible seniors; this represents around 45% the minimum wage earned by full-time working individuals (UK Government 2016b). Despite the fact that the UK state pension is perceived as an essential program to keep the well-being of British seniors, a very complex discussion concerning its sustainability and financial constraints have led to calls for a higher eligibility age since 2006 (Blake and Mayhew 2006). These calls, nonetheless, may not consider the welfare gains from the program that extend beyond the actuarial cost-benefit trade-offs. Some of those non-pecuniary welfare gains from pension programs can be for example represented by reductions in the levels of chronic stress. As a result, more evidence is needed on the potential benefits of these programs, which would lead to better-informed policy decisions.

This research paper contributes to the existing literature that measures the welfare gains of social programs by providing an understanding of how these programs reduce stress levels among seniors. One US study found that self-reported levels of health from Medicare extended beyond

[12] The United Kingdom government has been attempting to equalize the eligibility age for the state pension between men and women. As a consequence, the eligibility age for women born on or before 1950 is 60, for those born in 1951 and 1952 is 61, and those born after 1952 become eligible at age 62. In our data given the unbalanced sample across the eligibility threshold for those women born on or after 1951, we will be including only women born on or before 1950, implying that wwe will only consider the eligibility threshold of 60 years old for women.

the benefits attributable solely to increased access to health care (Card, Dobkin, and Maestas 2009). Another study (Dobbie and Song 2014) found that individuals who received Chapter 13 of Consumer Bankruptcy program (net of the income effect) had a 30% lower risk of death in the next five years when compared to those whose claims were dismissed. This study argues that this is a result of a potential stress relief effect of the Chapter 13, which reduced mortality among its beneficiaries. Other study showed that unemployment programs might have an impact on reducing suicide rate. The authors hypothesize that the pathway might be through reduction in mental conditions due to stress (Cylus, Glymour, and Avendano 2014).

Another study conducted in the state of Oregon in the US was made taking advantage of a random assignment for eligibility to apply for Medicaid among a group of uninsured low income individuals (Finkelstein et al. 2012). The study showed that beyond the increased insurance and health care utilization product of the eligibility to apply for Medicaid, they were also more likely to self-report better mental health and health status. It is possible that these later benefits come not from the income effect insurance, but from the actual fact of being covered, potentially being stress a mediating factor.

Other literature has shown that the mortality from unemployment can be partially attributable to higher levels of stress (Gardner and Oswald 2004). We did not identify any prior empirical studies describing the effect that a social program has on stress at the population level. In this paper, we estimate the effect that the state pension has on a physiological measure for stress among seniors in England. Our working hypothesis is that the state pension provides welfare gains that extend beyond the purely pecuniary benefits by providing stress reduction that leads to additional wellbeing and health benefits in the medium and long term. These benefits can be potentially observed through lower mortality rates (Gardner and Oswald 2004) and higher levels of preventive behavior, as shown later in chapter 4 of this dissertation[13].

We measure stress levels using a set of biomarkers available in the data and an index called allostatic load that has been extensively used in neurobiological sciences to measure stress. (Crimmins et al. 2003; Gersten, Dow, and Rosero-Bixby 2010; Juster, McEwen, and Lupien 2010; Bruce S. McEwen 2000; Rosero-Bixby and Dow 2009; T. E. Seeman, Singer, et al. 1997). The allostatic load metric is an empirical tool that signals the neuroendocrine response to stress in five different dimensions (i.e. cardiovascular, glucocorticoid, sympathetic, hypothalamic-pituitary-adrenal axis and immune activity) (Read and Grundy 2012).

Assessing stress levels in the senior population is key. Seniors face constant sources of stress due to a higher likelihood of financial vulnerability as they enter retirement, in addition to the emotional challenges of evolving changes in societal roles. Furthermore, some seniors can experience some level of cognitive decline, which reduces their ability to cope with stressful events (Rebok, Parisi, and Kueider 2014). As levels of stress increase with age, seniors are also more vulnerable to the health, cognitive and emotional consequences of higher levels of stress, and it is for this reason that stress among seniors represents an important policy target

The allostatic load measure is mostly used in neuropsychology and it is generally unfamiliar for most economists, but it is being increasingly used in other social science research fields (Bellatorre et al. 2011; Karlamanga, Gruenewald, and Seeman 2012; Kaestner et al. 2009; Kubzansky,

[13] Chapter 4 is the third aim of this dissertation an explores the effect that the allostatic load measure has on preventive behavior

Kawachi, and Sparrow 1999; Rosero-Bixby and Dow 2009; Seplaki et al. 2006) and public health literature (Peek et al. 2010). The main advantage of measuring the allostatic load is that it does not rely on questionnaire-based tests such as the General Health Questionnaire, avoiding self-report bias (Gardner and Oswald 2004).

This study takes advantage of the availability of the allostatic load measure in the data, and of the fact that the state pension program is an age-based social program with almost universal coverage[14]. Our identification strategy is based on assessing allostatic load levels in the neighborhood of the state pension eligibility age and therefore, the levels of chronic stress for those individuals right before the eligibility age for the state pension (before 65 years for men and before 60 for women in our sample[15]) compared to those just after they had become eligible to receive the state pension. In this regression discontinuity design (RDD), the age threshold offers a quasi-random assignment of the individuals in the neighborhood of the threshold, allowing us to measure discontinuities in the trajectory of the allostatic load measure. This allows us to suggest a causal link on the relationship between the state pension and the levels of allostatic load. RDD has been used extensively in the past to evaluate different outcomes for social programs whose eligibility of the program is age-based (Card, Dobkin, and Maestas 2008; Card, Dobkin, and Maestas 2009; Decker 2005; Fairlie, Kapur, and Gates 2011; Kadiyala and Strumpf 2012).

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[14] It is considered in UK government reports that practically all seniors eligible according to the age and sex criteria receive some state pension income. Potentially seniors who did not contribute for at least 10 or 11 years for women and men respectively and who did not accrue time towards the state pension with childcare, maternity leave or disability, or those who are non-legal residents of the UK might not be able to receive state pension income; however, this is generally a rare case.

[15] In recent years the eligibility age for women has been set to converge to the eligibility age for men and for both sexes to reach 67 in 2028. We only used women eligible for the state pension at 60 because those whose eligibility age has changed to 61 (born in 1951 or 1952) and 62 (born in 1953) comprise a small and unbalanced sample after the threshold that is not suitable for this type of analysis.

RDD requires the researcher to address two main issues. First, to ensure that there are no other concurrent factors that are also changing around the eligibility for the program and that might be driving the effects, leading to endogeneity problems. For our case, an important factor to take into account is retirement, which can occur around the age of eligibility for the state pension, potentially biasing the results of the RDD estimation. As we can observe the retirement status of these individuals, we disentangle the effect of retirement in the relationship between pension eligibility and the allostatic load[16]. Second, robustness checks on the functional form of the relationship between allostatic load and the state pension need to be performed to test the main assumption that the distribution of individuals in both sides of the threshold is balanced and that the effects are not cause by changes in the distribution of the age variable. For this reason, robustness checks using higher-level polynomials of the main independent variable are also performed[17]. By taking advantage of an RDD, this paper provides evidence of the effect that a social program, the state pension in the UK, has on the levels of stress as measured by the allostatic load indicators in the senior population. This design is possible thanks to the high-quality data obtained from the English Longitudinal Survey for Ageing (ELSA) which is comprised by a panel of individuals followed between 2002 and 2013 across six waves, three of them (2005, 2009 and 2013) including biomarker measurements (English Longitudinal Survey of Ageing 2001; Marmot et al. 2003; Phillips et al. 2012).

By measuring the levels of allostatic load, we are using an accepted physiological measure of chronic stress that has the strength of overcoming the measurement issues of proxying stress

[16] Becoming eligible for the state pension does not necessarily imply retirement. Some individuals continue working after becoming eligible and some others retire before.
[17] In this research we use a first-, second- and third-degree polynomial of the age variable to account for potential artifacts introduced by the functional form of the relationship between allostatic load and age.

through exposure or self-report as found in previous literature (Costa and Kahn 2010; Rosero-Bixby and Dow 2009).

In this research, we only use individuals and waves in which biomarkers were taken with the aim of assessing their levels of allostatic load. Despite the UK state pension program extends to the entire UK, because our data is limited to England, we will only be able to generate results for England, and in particular we observed that the data on biomarkers were collected in a sample of healthier, younger and more affluent subpopulation of seniors (The study sample comprises 78% of the survey sample). Because seniors in more vulnerable conditions and likely to have higher levels of chronic stress are not observed, we believe our results are even more important as they likely underestimate the effect of the state pension on chronic stress.

As previously discussed, the importance of measuring the effect of the state pension on stress relies on the extent to which the welfare gains of this program could be underestimated. Pension programs can directly reduce financial stress among seniors. Moreover, the fact that the state pension is a regular and steady source reduces financial uncertainty. Second, the income effect from the state pension can facilitate maintaining financial independence from children and other members of the family, which can be reflected in lower levels of stress. However, it should be recognized that the additional income might lead to seniors facing problems with their children who want financial support; thereby increasing the levels of chronic stress. (Estes et al. 2006; Lachs and Pillemer 1995).

In this research, we find that the levels of allostatic load are reduced by between 11% and 17% depending on the specification used for male respondents whose household wealth is lower than

£35,000. This effect is not observed in respondents living in households with wealth above £35,000, which supports the hypothesis that these effects are mainly driven by the effect of the state pension in reducing financial stress. Interestingly, our results reveal that women living in households with wealth under £35,000 also experience reductions in the allostatic load levels at the eligibility age only when living alone.

We performed robustness checks in order to evaluate the effect of retirement on stress as time preferences might affect the levels of stress experienced at the eligibility age. We find that retirement is positively correlated with the allostatic load measure. When this variable is not included in the model, the effect becomes smaller, supporting the argument that retirement does not represent a confounder in this relationship. Individuals who made larger National Insurance Contributions (for the S2P scheme of the state pension) or contributed for longer (for both the basic and the S2P scheme) to accrue a higher state pension when they become eligible, might have lower time discount rates, be more risk-averse, or have stronger preferences for a higher permanent income. This can in turn, affect the levels of allostatic load of these individuals. We cannot observe the frequency and type of National Insurance Contributions that these individuals made. However, we can observe the resulting amount of the state pension. Consequently, we included the amount of the state pension as a control variable. Other robustness checks commonly applied in the empirical literature in RDD to assess the functional form of the age variable and the distributional assumptions of other covariates were carried out with consistent results.

Our research helps us to conclude that the UK state pension can improve the levels of stress among English male seniors living in less wealthy households by reducing their allostatic load levels by between 11% and 17%, depending on the specification. The state pension also reduces the allostatic load between 26% and 34% among women who live in less wealthy households and who also live alone.

The impact of changes in the allostatic load can be hard to grasp since it is not a widely used metric yet. However, prior studies might shed a light on the significance of these findings. Prior research has found that the differences in allostatic load levels in the United States between white and African Americans reach 0.45 in average (Geronimus et al. 2006). Our results show that the eligibility for the state pension changes the allostatic load levels among men living in less wealthy households by between 0.24 and 0,36, which is equivalent to between 50% and 75% the effect of race in the allostatic load in the US. The effect among women living alone and in les wealthy households is even higher.

Another study (Schulz et al. 2012) performed in the US shows that residents living in neighborhoods with 20% of households below the poverty line experienced levels of allostatic load 0.2 higher than the average person living in neighborhoods with less than 20% of households below the poverty line. This could imply that the reductions in stress levels for men living in less wealthy households related to the eligibility for the state pension are equivalent or even higher, than those experienced when neighborhood poverty is reduced. Other study (Karlamangla, Singer, and Seeman 2006) showed that increases in the allostatic load decreases the 3-year mortality by 10%. This implies that potentially the state pension eligibility might increase the life expectancy at the age of eligibility.

These results shed some light on a potential policy intervention that balances the trade-off between the necessary fiscal sustainability and the well-being of the recipients of the UK state pension.

3.2 UK State Pension

The state pension in the UK is a social program aimed at providing financial protection to seniors after their eligibility age. To be eligible for the UK State pension, an individual must 1) meet the age requirement, and 2) having made National Insurance Contributions for at least 11 years in the case of men and 10 years in the case of women. There are circumstances under which some people might accrue time towards obtaining the state pension without making National Insurance Contributions such as full-time credit training, child care, or obtaining income support as carer of a sick person, being unemployed, being on maternity leave, having a disability or being classified as not fit to work. Also spouses of armed forces members posted overseas get credit towards the UK State pension (NIDirect 2010; UK Government 2016a). Depending on the length of her lifetime contributions, an individual is paid in 2016 the basic state pension with a maximum of £115.95 a week for those who contributed during 30 years (UK Government 2016c). For people who contributed less than 30 years, each year of contribution adds a 1/30 of the full state pension. Virtually all residents of the United Kingdom are eligible[18], based on their National Insurance Contribution, to receive the minimum UK state pension at the eligibility age (Blundell and Johnson 1998). The age of eligibility for the state pension varies depending on the sex and year of birth of the person. Men are eligible at age 65. Women born on or before 1950 are eligible at age 60. However, the government has subsequently tried to converge eligibility criteria for men and women. For this reason, women born in 1951 and 1952 are eligible at age 61, and women born in

[18] Practically all seniors eligible according to the age and sex criteria receive some state pension income (Institute for Fiscal Studies 2010). Potentially seniors who did not contribute for at least 10 or 11 years for women and men respectively and who did not accrue time towards the state pension with childcare, maternity leave or disability, or those who are non-legal residents of the UK might not be able to receive state pension income; however, this is generally a rare case.

1953 and after are eligible at age 62. Because we did not have a balanced sample before and after the threshold for women born on or after 1951, we excluded them from the data. Therefore, our analyses for women are restricted only to those who were born on or before 1950 and therefore, whose eligibility threshold is set at 60 years old. As there is no reason to believe that this subset of women are systematically different from those born before other than on the eligibility age for the state pension, we believe this exclusion should not affect our analyses.

3.3 Data and study sample

We are using data from the English Longitudinal Study of Aging (ELSA). ELSA is a 6-wave nationally representative longitudinal survey of the non-institutionalized population above 50 in England jointly conducted by the University College of London, the Institute for Fiscal Studies, and the National Center for Social Research based on the Health Survey for England (Marmot et al. 2003; Phillips et al. 2012). We are using this survey because it includes biomarker information for the individuals assessed in waves 2, 4 and 6 (2005, 2009 and 2013), which allows us to create an allostatic load metric as a proxy for chronic stress.

The initial ELSA sampling framework was based on all the households that responded the Health Survey for England (HSE) of 1998, 1999, or 2001 with a total of 23,132 households interviewed. HSE is a cross-sectional nationally representative survey of the non-institutionalized population conducted every two years to assess the health status of the population of England. The HSE population involves a multistage probability sampling approach based on postal codes and households (English Longitudinal Survey of Ageing 2001; Rachel Craig and Jennifer 2014). Of all the households that responded these three HSE surveys, all households with at least one eligible member were defined as eligible households in the ELSA survey. An eligible member was defined as anyone in the household born before February 29^{th}, 1952 (17,744 individuals) and who agreed to be re-contacted (11,391 individuals). Younger partners of eligible household members were also included in the survey, but they are not included in our study since they are not being taken samples for assessment of biomarkers. Potential biases are introduced by this condition, especially the possibility of self-selection by capturing healthier individuals who are more likely and more willing to be re-contacted.

All eligible individuals (n=11,391 at wave 1) were contacted and followed up during six biennial waves when possible. Of the initial 11,391 eligible individuals at wave 1, 8,781 (82%) were followed-up during the second wave, when the first round of biomarkers samples were taken. Subsequent cohorts of individuals ("refreshment samples") from the HSE were added in 2007 at wave 3 (n=1,276), in 2009 at wave 4 (n=1,219) and in 2013 at wave 6 (n=2,253) in order to maintain a representative sample of the population older than 50 given the attrition of the survey.

The ELSA survey included biometric and anthropometric measurements at wave 2, 4 and 6. In each of the waves, all participants who did not have an exclusion criteria for performing biometric and/or anthropometric measures were invited to schedule a nurse visit to be part of the "nurse subsample", where all biometric and anthropometric measurements were taken. The exclusion criteria were 1) Not providing written consent for the measurements; 2) The participant was on anticoagulant medication or had a clotting or bleeding disorder (for blood samples). In addition to these exclusion criteria, for blood samples requiring fasting, they were not taken on respondents who 1) were over 80 years old; 2) seemed frail or ever had a seizure; or 3) the nurse had concerns about asking them to fast for any other specific health concern. Fasting was defined as having had any food or drink except water five hours prior to the blood test (de Oliveira et al. 2008). Once again, the bias introduced by the eligibility criteria for the biometric and anthropometric measurements to enroll healthier subjects will be assessed in this study.

Women who are born on and after 1951 become eligible after 60 years old, which implies that we would need to conduct separate analyses for this subset of women. Given that a key condition for RDD is to have balanced samples in both sides of the threshold, and this was not possible given the small sample size, we decide to exclude all women born on or after 1951, corresponding to 1,919 individuals. As there is no reason to believe that this subset of women are systematically different from those born before other than on the eligibility age for the state pension, we believe this exclusion should not affect our analyses. Consequently, our final dataset contains 16,909 individuals.

More information on the ELSA survey can be found in the internal ELSA documentation (Marmot et al. 2003; Phillips et al. 2012) or in the ELSA website at www.elsa-project.ac.uk/. Specific weights for the subsample of individuals with biomarkers taken are available in the dataset and used accordingly.

In table 3.1, we display the descriptive statistics of the allostatic load and the independent variables. To ensure the smoothness of the age profiles of each of the independent variables across the state pension eligibility age threshold, we conducted smoothness tests between each covariate and the age eligibility threshold. These tests consist of linear regressions of the eligibility threshold on each independent variable controlling for a third-degree polynomial of the age-centered variable, and a dummy variable for wave of the survey. The only variable that displayed a statistically significant change ($p<0.05$) at the age eligibility threshold was retirement, which is not surprising as retirement can occur around the state pension eligibility age.

Table 3.1 Descriptive statistics and smoothness test for the outcome and independent variables

Variables	Descriptive statistics of the study sample		Descriptive statistics of the full sample		*p*	Smoothness of the independent variable		
	n	%	n	%		Eligibility for state pension	SE	*P*
Allostatic load								
0	3,870	22.89	5,881	27.21	<0.01	N/A		
1-2	7,796	46.11	9,926	45.92				
3-4	4,095	24.22	4,648	21.50				
More than 4	1,148	6.79	1,161	5.37				
Age								
50-59	3,616	21.39	4,418	20.44	<0.01	N/A		
60-69	6,904	40.83	8,456	39.12				
70-79	4,562	26.98	6,058	28.03				
80 or more	1,827	10.80	2,684	12.42				
Sex								
Male	8,509	50.32	10,728	49.63	0.79	N/A		
Female	8,400	49.68	10,888	50.37				
Region								
North-East	1,075	6.36	1,369	6.33	0.96	-0.02	0.1	0.83
North-West	1,987	11.75	2,505	11.59				
Yorkshire and the Humber	1,813	10.72	2,312	10.70				
East Midlands	1,720	10.17	2,288	10.59				
West Midlands	1,903	11.25	2,353	10.89				
East of England	2,085	12.33	2,717	12.57				
London	1,385	8.19	1,804	8.35				
South-East	2,910	17.21	3,675	17.01				
South-West	2,029	12.00	2,588	11.98				

Note: Each column includes men aged 50 to 99 and women aged 53 to 99 and displays the descriptive statistics of each of the independent variables. The first set of columns presents data on the study sample equal to 16,909 respondents. The second set of columns represents the full sample of 21,616 individuals in the survey (excluding women born on or after 1951) and the p-value represents the results of a bivariate test depicting the differences between the full sample and the sample used in the study. The smoothness of the independent variables is assessed by regressing the eligibility threshold for state pension (Based on age depending on sex and year of birth) on each variable of the study sample, controlling for a dummy for wave and a third-degree polynomial for the centered age variable. No smoothness test was carried out for the dependent variable, and the independent variables age, sex and amount of yearly state pension. The amount of state pension is GBP per year. Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, dementia, and arthritis.

Table 3.1 Descriptive statistics and smoothness test for the outcome and independent variables (cont.)

Variables	Descriptive statistics of the study sample		Descriptive statistics of the full sample		*p*	Smoothness of the independent variable		
	n	%	n	%		Eligibility for state pension	SE	*P*
Marital status								
Living without partner	5,535	32.75	7,289	33.73	<0.01	0.02	0.0	0.11
Living with partner	11,367	67.25	14,319	66.27				
Total household wealth (GBP)								
Less than 35,000	8,749	51.74	11,474	53.08	<0.01	1.74	1.01	0.09
35,000-60,000	1,839	10.88	2,302	10.65				
60,000-100,000	2,012	11.90	2,512	11.62				
More than 100,000	4,309	25.48	5,328	24.65				
Amount of state pension								
<4,000	8,996	53.22	11,328	52.42	<0.01		N/A	
4,000 - 8,000.	6,540	38.69	8,467	39.18				
>8,000	1,369	8.10	1,817	8.41				
Education								
No qualification	5,604	34.01	7,433	35.43	<0.01	0.00	0.07	0.96
Foreign	1,211	7.35	1,555	7.41				
NVQ1	705	4.28	925	4.41				
NVQ2	3,064	18.59	3,783	18.03				
NVQ3	1,177	7.14	1,432	6.83				
NVQ4	2,244	13.62	2,807	13.38				
NVQ5	2,473	15.01	3,042	14.50				

Note: Each column includes men aged 50 to 99 and women aged 53 to 99 and displays the descriptive statistics of each of the independent variables. The first set of columns presents data on the study sample equal to 16,909 respondents. The second set of columns represents the full sample of 21,616 individuals in the survey (excluding women born on or after 1951) and the p-value represents the results of a bivariate test depicting the differences between the full sample and the sample used in the study. The smoothness of the independent variables is assessed by regressing the eligibility threshold for state pension (Based on age depending on sex and year of birth) on each variable of the study sample, controlling for a dummy for wave and a third-degree polynomial for the centered age variable. No smoothness test was carried out for the dependent variable, and the independent variables age, sex and amount of yearly state pension. The amount of state pension is GBP per year. Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, dementia, and arthritis.

Table 3.1 Descriptive statistics and smoothness test for the outcome and independent variables (cont.)

Variables	Descriptive statistics of the study sample		Descriptive statistics of the full sample		*p*	Smoothness of the independent variable		
	n	%	n	%		Eligibility for state pension	SE	*P*
Retired								
Yes	10,184	60.23	13,306	61.56	<0.01	0.30	0.0	<0.01
No	6,725	39.77	8,310	38.44				
Size of the household								
0	3,931	23.25	5,217	24.13				
1	9,913	58.63	12,554	58.08				
2	1,959	11.59	2,441	11.29	<0.01	0.02	0.0	0.43
3-4	1,000	5.91	1,271	5.88				
More than 4	106	0.63	133	0.62				
Stressful episodes								
Yes	4,970	29.39	6,269	29.00	0.02	-0.03	0.0	0.06
No	11,939	70.61	15,347	71.00				
Number of comorbidities								
0	6,475	38.29	7,817	36.16				
1-2	4,620	27.32	9,268	42.88	<0.01	-0.07	0.04	0.09
More than 2	5,814	34.38	4,531	20.96				
Cognitive test (word recall)								
Less than 10	5,614	34.65	7527.00	36.57				
10-15	9,583	59.14	11841.00	57.53	<0.01	0.09	0.10	0.33
16-20	1,007	6.21	1216.00	5.91				
Cognitive test (date recall)								
Less than 4	3,249	19.34	4273.00	19.93	<0.01	0.01	0.01	0.64
4 (maximum)	13,554	80.66	17168.00	80.07				
Difficulty walking 100 yards								
Yes	1,351	7.99	2172.00	10.05	<0.01	0.00	0.01	0.62
No	15,558	92.01	19444.00	89.95				

Note: Each column includes men aged 50 to 99 and women aged 53 to 99 and displays the descriptive statistics of each of the independent variables. The first set of columns presents data on the study sample equal to 16,909 respondents. The second set of columns represents the full sample of 21,616 individuals in the survey (excluding women born on or after 1951) and the p-value represents the results of a bivariate test depicting the differences between the full sample and the sample used in the study. The smoothness of the independent variables is assessed by regressing the eligibility threshold for state pension (Based on age depending on sex and year of birth) on each variable of the study sample, controlling for a dummy for wave and a third-degree polynomial for the centered age variable. No smoothness test was carried out for the dependent variable, and the independent variables age, sex and amount of yearly state pension. The amount of state pension is GBP per year. Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, dementia, and arthritis.

The ELSA survey is publicly available through online registration and acceptance of the terms and conditions (Erens and Primatesta 1999; Prior et al. 2003; Taylor, Conway, and Lessof 2003). The Institutional Review Board (IRB) of the Johns Hopkins School of Public Health determined this research project and the data proposed to be used as “not human subjects research” on December 3rd, 2014 and therefore it does not require IRB oversight.

3.3.1 Sample selection bias

Given that only seniors who were fit enough to undergo the biomarker tests and who agreed to be tested are included in this sample, we are likely using a subsample of younger, healthier, wealthier, more likely to be working, more likely to be living with a partner, and more educated. Table 3.1 shows the differences between the study sample and the full sample with all the individuals included in the ELSA survey across the three waves (including those who don’t have biomarker measurements). The study sample includes 78% of the full sample. This type of sample selection bias is inherent to conducting research using biomarkers in senior populations. The selection bias in our study sample is likely to bias downwards the effects found as the population we are observing is generally more affluent and healthier than the general population. Any relationship of the independent variables with the allostatic load is therefore likely to be equal or smaller than what would have been seen in a less healthy population (T. E. Seeman, Singer, et al. 1997; Teresa E. Seeman et al. 2001).

3.3.2 Outcome: allostatic load

A recurrent problem to study stress in the general population has been the difficulty in its measurement. Stress has been traditionally measured by self-report (Robert Wood Johnson

Foundation/Harvard School of Public Health 2014) or through proxies such as being a war veteran (Costa and Kahn 2010), but self-perception of stress is commonly masked by several factors, including coping strategies, which can confound any self-reported stress measurements. The allostatic load variable provides information on a more physiological dimension of the levels of chronic stress, which improves the measurement of this factor. For this reason, there is an increasing trend, especially in epidemiological studies, to recognize not only the role of stress on different conditions and behaviors, but also to measure it in a more accurate way and create a more precise and objective measurement of stress. Prior literature in neuropsychology has used the allostatic load variable since 1993 (B. S. McEwen and Stellar 1993), and a growing number of studies in epidemiology and public health have used it to measure stress at the population level (Kirschbaum et al. 1999; Read and Grundy 2014).

In this research study, the allostatic load measure has been taken as the approach to measure stress given that it is a valid and reliable, well-accepted, and measurable method (Goldman et al. 2005; Wippert et al. 2014; Teresa E. Seeman et al. 2004; Howard and Sparks 2016; T. E. Seeman, Singer, et al. 1997; Gersten 2008). The allostatic load index has been widely used to measure chronic stress levels because it shows correlation with steady levels of stress response in different validation studies (Bruce S. McEwen 2000; T. E. Seeman, McEwen, et al. 1997). Most of the allostatic load literature defines an abnormal biomarker as any with a value above the 75th percentile (or otherwise below the 25th percentile for some specific biomarkers) of the empirical distribution of that biomarker in the population. Each abnormal biomarker adds up one unit towards the allostatic load metric. Studies using the allostatic load metric tend to be heterogeneous on the number and the type of biomarkers that are used across different studies. Which biomarkers are used often depends on the availability of those biometric markers in different surveys; however, the findings have proven to be robust across different indexes (Juster, McEwen, and Lupien 2010).

In this study, the cut-off points to determine an abnormal biomarker are similarly set at the value corresponding to the 75th percentile of the distribution of the biomarker in the population stratified by sex. The reason to stratify the estimation of abnormal values for each biomarker by sex is intended to avoid penalizing one sex category when both men and women are assessed using the same thresholds. It is for this reason that we decided to stratify the thresholds, which are presented in table 3.2.

Table 3.2 Cut-off points for determining an abnormal biomarker

	Wave 2		**Wave 4**		**Wave 6**	
	Female	**Male**	**Female**	**Male**	**Female**	**Male**
Systolic blood pressure (mm Hg)	151.0	150.0	146.0	148.0	145.0	146.0
Diastolic blood pressure (mm Hg)	83.0	84.0	82.0	83.0	82.0	82.0
HbA1c (mmol/mol)*	5.7	5.8	6.0	6.0	42.0	43.0
BMI	31.1	30.2	31.4	30.5	31.4	30.6
Waist (cm)	98.5	108.5	100.8	109.4	100.2	109.2
Cholesterol (mmol/L)	6.9	6.3	6.6	6.0	6.6	6.0
C-Reactive Protein (mg/L)	3.5	2.9	4.3	3.6	3.5	2.9
Fibrinogen (g/L)	3.7	3.5	3.7	3.6	3.3	3.2

Note: The cut-off points are estimated at the value of the 75th percentile of the population distribution of each biomarker. *For waves 2 and 4, the measurement unit for HbA1c is percentage whereas for wave 6 is mmol/mol.

The allostatic load metric is an empirical tool that signals the neuroendocrine response of the body to stress. Biomarkers used to build the allostatic load metric mostly take into account five dimensions of the stress response. This survey has been used in the past to carry out research on allostatic load at the population level (Read and Grundy 2014). Here, we list the biomarkers used in this study by dimension: 1) Cardiovascular activity, measured through the systolic and diastolic blood pressure. 2) Glucocorticoid activity is obtained by measuring the levels of total cholesterol, glycated hemoglobin, BMI and the waist diameter. 3) Finally, fibrinogen and the C-reactive protein is a proxy for inflammatory and immune activity. (Read and Grundy 2012).

External stressors, individual factors and the behavioral responses to those factors determine the level of allostatic load of an individual (B. S. McEwen 1998). These three aspects of the response to stress affect the four dimensions of the key factors for successful ageing: physical, cognitive, emotional, and behavioral factors (Rebok, Parisi, and Kueider 2014).

These factors module the physiological response that is observed as an increased allostasis rate and therefore, a higher allostatic load. In this paper, the number of abnormal biomarkers (out of eight) measured for each wave and individual was defined as the allostatic load measure. Even though there is discussion about whether each of the allostatic load biomarkers should have differential weightings, evidence shows that the simple count of abnormal biomarkers is highly predictive of a wide range of outcomes (Read and Grundy 2012; Seplaki et al. 2005). Similarly to prior work (Juster, McEwen, and Lupien 2010), eight different biomarkers are used to estimate the allostatic load levels across the three waves.

The first construct validity study using the allostatic load measure was made by Seeman et al (T. E. Seeman, Singer, et al. 1997) in which they showed the gradient existing between the allostatic load measure as a proxy for stress and the cognitive and functional scores of a sample of seniors in the US. Factor analysis has been conducted with the allostatic load measure, showing that it is comprised by one single underlying factor (Howard and Sparks 2016), evidencing the unidimensionality of the measure when being used to measure chronic stress at the population level. In terms of predictive validity, the allostatic load has proved to predict functionality, mortality, and cognition (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2002; Crimmins, Kim, and Seeman 2009; Goldman et al. 2006). One study found that 35.4% of the variance in mortality risk attributable to education is captured by the effect of the allostatic load (Teresa E. Seeman et al. 2004).

Regarding reliability of the allostatic load measure, one study found that the test-retest reliability of allostatic load comparing it with the Trierer Inventory of Chronic Stress produces an intraclass correlation coefficient of 0.89 (Wippert et al. 2014). Internal consistency studies show that the Alpha internal consistency reliability score of the allostatic load measure reaches 0.79 (Goldman et al. 2005).

A literature review carried out by Juster et al (Juster, McEwen, and Lupien 2010) shows that the body of research on allostatic load has produced reliable and consistent results ranging from assessing the stress caused by racial differences (Geronimus et al. 2006) to the effectiveness of anxiolytic drugs on cognition and stress (Soria et al. 2015).

3.3.3 Independent variables

Wave was include as a control variable. All control variables are self-reported and classified into the following vectors:

3.3.3.1 Demographic variables

Age: Allostatic load can vary over time in the same individual. To control for this fact, the variable age will be included in a linear form as most of the allostatic load literature uses it (Crimmins et al. 2003). In this research paper, the assignment rule is based on age, as an external source of variation. Therefore, the age variable is centered around the eligibility age (depending on the age and sex of the respondent as discussed before). Robustness checks including second- and third-degree polynomials of the age variable were also performed with the aim of ensuring that the functional form of the age variable does not determine the results.

Sex: Allostatic load as well as the demand for prevention might differ by sex as shown in prior research (Seplaki et al. 2004).

Government Office Region: This variable accounts for the nine administrative regions of England, which can be representative of differences on health outcomes and deprivation during childhood (Woods et al. 2005). Despite the fact that we do not have the location of the respondent during her childhood, this variable might be relevant because it provides a proxy for differences in the current environment related to geographical variation, which also affect chronic stress levels (Dahl 2004).

3.3.3.2 Socioeconomic variables

Marital status: This is an important variable because prior research shows evidence on the relationship of marital status with allostatic load levels and preventive behavior (Cramm and Nieboer 2012; Gersten, Dow, and Rosero-Bixby 2010). With the aim of simplifying the analysis, a dichotomous variable was built defining whether the individual lives with a partner (married, living with a permanent partner) or not (never married, widowed or divorced).

Belonging to a household with wealth higher than £35,000: Wealth was measured as a dichotomous variable signaling whether the household wealth where the respondent lives is located above or below the median of wealth estimated (£35,000). Similar to the work of Hamer

et al (Hamer, de Oliveira, and Demakakos 2014; Marmot et al. 2003), wealth was estimated as a monetized measure (in Great Britain Pounds) of the total household wealth net of household debt and excluding the participant's value of the home (with or without mortgage) and physical wealth such as artwork or jewelry. Different from what was done in Hamer et al study (Hamer and Stamatakis 2013), we included financial assets such as savings, and business assets for considering them an important part of the total wealth variable. Wealth is a more appropriate variable to measure the socioeconomic conditions of the respondent as seniors often count only partially on regular sources of income. Prior research has found there is a linear relationship of wealth with preventive behavior and allostatic load (Dowd and Goldman 2006; Evans and Schamberg 2009). Results in graphs were also shown comparing the top and lowest decile of the distribution of the wealth variable.

Amount of the pension received: As mentioned before, there is variability in the amounts earned from the state pension depending on the time of contribution to National Insurance payments. In addition, some individuals have also made voluntary contributions through S2P, which are represented as higher amounts of state pension when they become eligible. Because we cannot discriminate between the amount of basic state pension and S2P, and because there is arguably a possibility in which some characteristics of the individuals who contribute for longer might be related to the levels of allostatic load of the individuals (e.g. time preferences or risk aversion), we decided to introduce this variable as a control.

Education level: Education is found to be correlated with allostatic load in prior research studies (Kubzansky, Kawachi, and Sparrow 1999). In the population that pertains to this research, education is relatively exogenous as the educational choices were taken several decades before.

This variable was included in its original format which is a variable with eight categories (no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate) equivalent to the National Vocational Qualification (NVQ1-5) official categorization of England (UK Government 2015).

Retirement: We included a binary variable accounting for whether the respondent reported to be retired at the time of the survey, as we anticipate this can be an important factor of stress. This is a dichotomous variable and does not account for different retirement statuses.

Size of the household: The size of the household is an important variable that is often used in research carried out in senior populations because it proxies the social capital and the family support of the respondent (Trujillo, Hyder, and Steinhardt 2011).

Having experienced a highly stressful episode: This variable has been used in the past as a proxy for stress in previous research (Costa and Kahn 2010). It can be a cause of chronic stress due to the trauma experienced early during the childhood, which previous research has shown is correlated with higher levels of allostatic load later in life (Turner, Thomas, and Brown 2016; Tomasdottir et al. 2015). This is a binary variable that accounts for whether any of the following events took place: 1) When aged under 16, parents who drank excessively, took drugs or had mental health problems; 2) Having had a husband, wife, partner or child who has been addicted to drugs or alcohol; 3) Ever being a victim of sexual assault (including rape or harassment); 4) Other than in war or military action, having ever witnessed an accident or violent act in which someone was killed or seriously wounded; 5) Having ever provided long-term care to a disabled or impaired relative or friend; and 6) Having ever experienced severe financial hardship.

3.3.3.3 Health and cognition variables

Number of comorbidities: Comorbidities are an important determinant of preventive behavior (Seplaki et al. 2005; S. L. Szanton et al. 2009). We included a variable accounting for the number of comorbidities that the individual has at each survey as this is a recognized proxy measure for the degree of comorbidity of the individual (Wolff, Starfield, and Anderson 2002). This measure includes the comorbidities that are deemed to produce the higher burden of disease in the United Kingdom (C. J. L. Murray and Lopez 2013): angina, myocardial infarction history, congestive failure, stroke history, lung disease or cancer. We also included the following comorbidities: high blood pressure, diabetes, high cholesterol, dementia, and arthritis. They were also included given its high prevalence and burden. These conditions were all self-reported and were summarized in a variable that summed up the number of these conditions present for each individual at each wave.

Cognitive skills: Allostatic load affects cognitive skills according to previous studies (Seplaki et al. 2005). As a consequence, cognitive and mental function was incorporated using two memory indices from the ELSA survey that have been used and validated in other population-level surveys (Ofstedal, Fisher, and Herzog 2005) for measuring one dimension of cognition. The first one is the date recall test, which is a 4-item variable accounting for recall of the current date (day, day of the week, month and year). The second one is the word recall test, which result is the sum of the number of words recalled immediately and after a delay (0 to 10 each for a total of 20).

Difficulty walking 100 yards: This variable accounts for health issues that prevent the person to walk 100 yards and that would be expected to last more than 3 months. This constitutes a control variable for the level of disability experienced by the individual.

3.4 Empirical strategy

The regression discontinuity design (RDD) has been used in prior research studies evaluating the effect of social programs on health services research where eligibility of the program is age-based (Card, Dobkin, and Maestas 2008; Card, Dobkin, and Maestas 2009; Decker 2005; Fairlie, Kapur, and Gates 2011; Kadiyala and Strumpf 2012). Given that the state pension is also an age-based program an therefore, age provides and exogenous source of variability, we take advantage of this method to evaluate its effect on the allostatic load measure.

In this study, we carried out a linear regression model that estimates the effect of the eligibility to receive the UK state pension on the allostatic load metric.

$$Allostatic\ load = \alpha + f(centered\ age_i, \delta) + \beta\ Eligibility_i + \gamma X_i + \varepsilon_i$$

Where $f(centered\ age_i)$, is a function of the age variable centered at the specific eligibility age for each individual (based on their year of birth and sex as discussed) with a first, second and third-degree polynomial δ of the age-centered variable. Other control variables are included in this analysis and presented in table 3.1[19]. The existence of an eligibility threshold to receive the UK state pension benefit provides an exogenous source of exogenous variation around both sides of

[19] In appendix 3.1, we present the full estimation with the three different specifications for the age variable. These results are not stratified by wealth category and sex.

the threshold allowing us to measure a local effect. The advantage of this design relies on the core assumption that individuals in the neighborhood of the threshold are similar in both observable and unobservable factors and that the trajectory of those factors is smooth across the threshold. Therefore, any significant change in a variable across the threshold should only be due to the fact that the individual becomes eligible for the UK state pension. This is the first study that we are aware of, that evaluates the effect of a pension program on the allostatic load using this empirical approach.

Individuals anticipating the loss of permanent income at retirement smooth their consumption paths by contributing to pension schemes. Because the contribution for pension schemes is time-based, we would not expect that people change abruptly their behavior or allostatic load levels right before reaching the eligibility age. However, risk-averse individuals might make higher contributions to the S2P program or be more likely to accrue the 30 years that are required to have the maximum state pension. To account for these facts, we are including a control for the amount of the state pension per year.

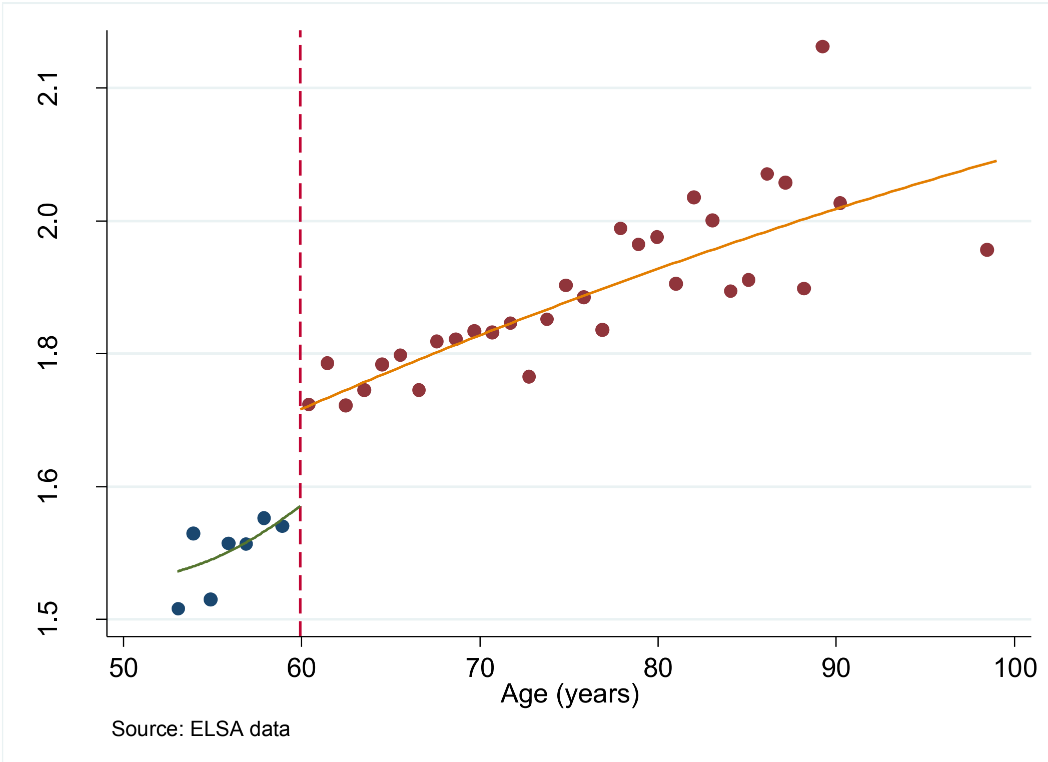
3.5 Results

In tables 3.3 and 3.4 (for females and males, respectively) as well as figures 3.1 to 3.4 we display the heterogeneity of the effect of the state pension program on the allostatic load metric across household wealth categories and sex. We found a statistically significant decrease on the levels of allostatic load between 11% and 17% on the average pre-eligibility allostatic load levels, only for males living in households with wealth below £35,000 (see figure 3.4). This finding suggests that the effect of the state pension on the allostatic load causes a decrease on the levels of stress of vulnerable individuals, particularly men. This effect is not observed on individuals with household wealth levels above £35,000 or among women[20]. The predicted values of the allostatic load measure[21] experience a significant reduction in the allostatic load at the eligibility age for male respondents living in households with wealth less than £35,000. For female respondents living in households with less than £35,000, such drop is not evident in these initial analyses (figure 3.2). For both men and women living in households with household wealth above £35,000, we observe non-significant changes in the allostatic load measure at the eligibility age (figures 3.1 and 3.3).

[20] See section 3.5.2 for robustness checks on the case of women

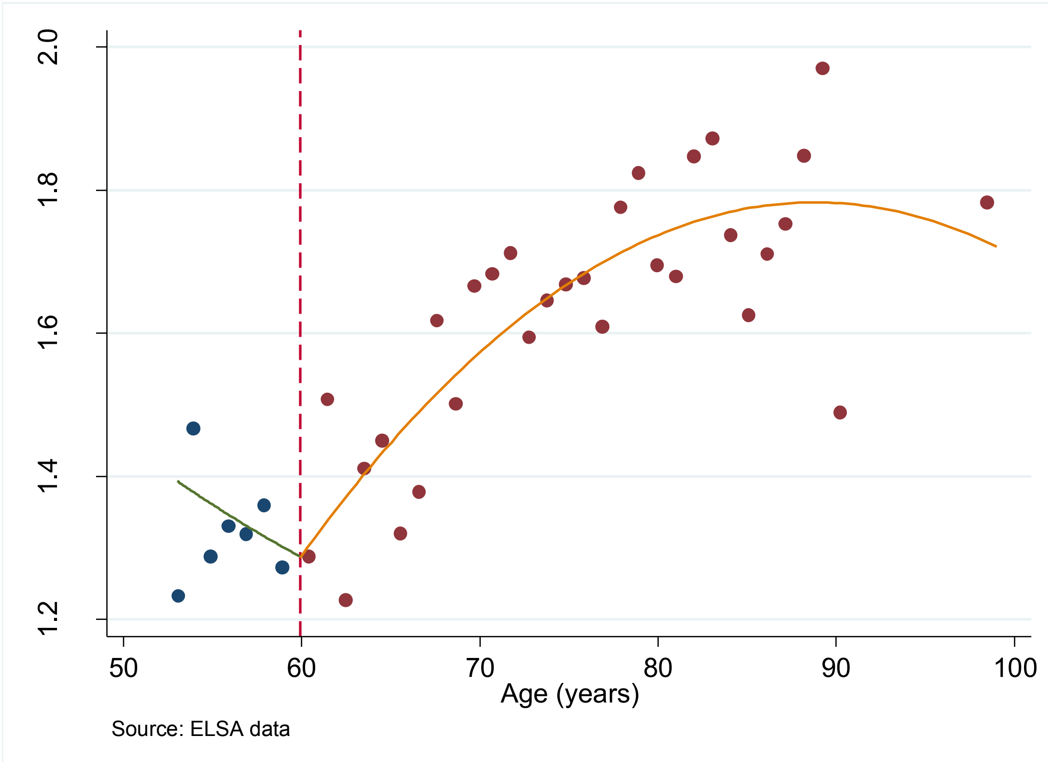
[21] Controlling for all the above described variables by category of sex and household wealth (higher or lower than £35,000).

Figure 3.1 Predicted values of the allostatic load metric for women who reach the eligibility age at 60 years old and live in households with wealth higher than £35,000



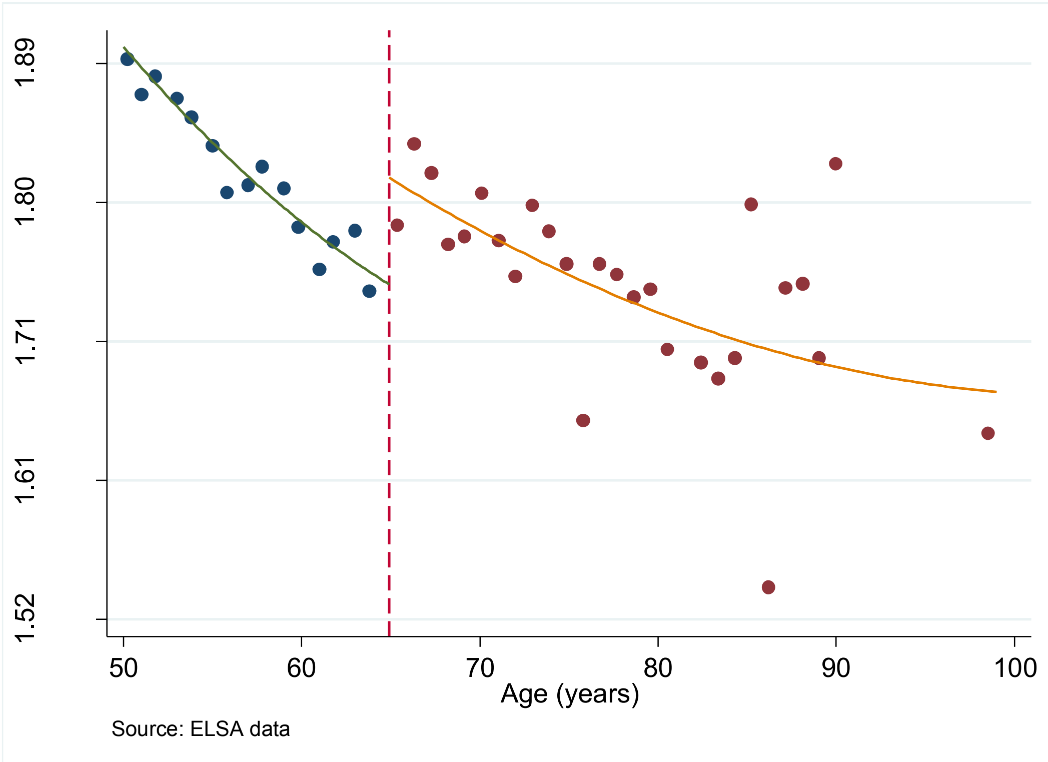
Note: Predicted values of the allostatic load measure and age for 7,935 women (born before 1951) with an age eligibility threshold at age 60. The predicted values are obtained from the regression of an indicator for the eligibility age, a first-degree polynomial of the age variable centered at the state pension eligibility age (60 years old), and regression controls. Regression controls include governmental office region, marital status, total household wealth, amount of state pension, level of education, retirement status, size of the household, having experienced stressful episodes, number of comorbidities, two cognition controls (date and number of words) and whether the respondent has difficulty walking 100 yards and wave.

Figure 3.2 Predicted values of the allostatic load metric for women who reach the eligibility age at 60 years old and live in households with wealth lower than £35,000.



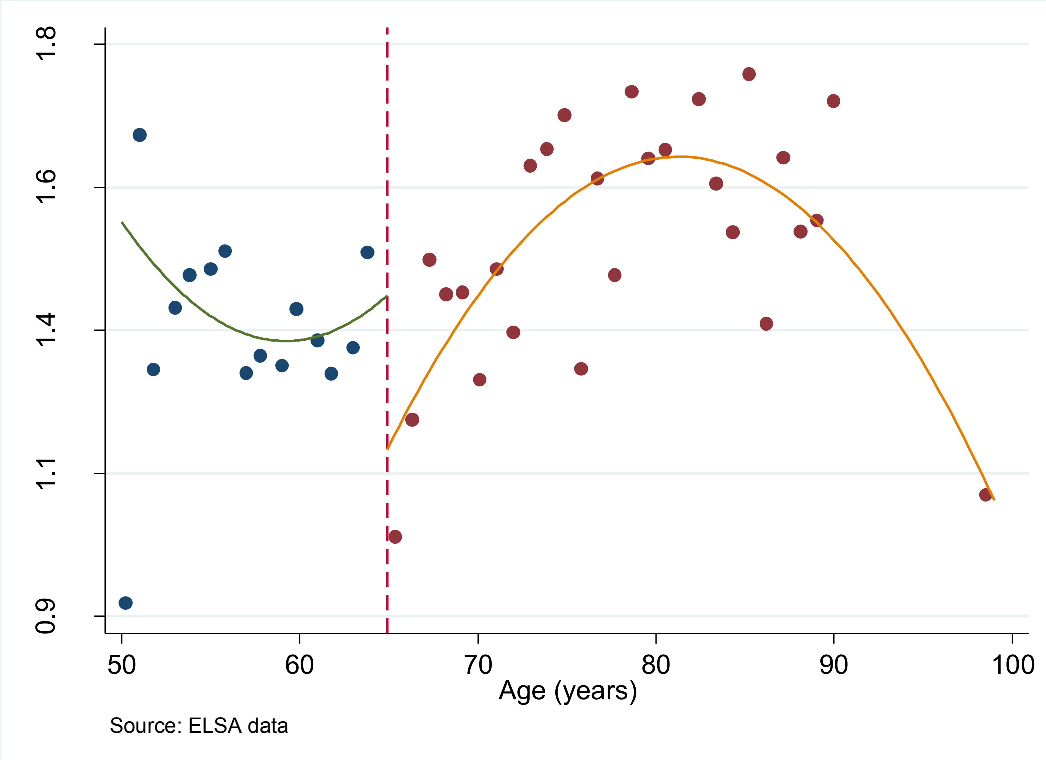
Note: Predicted values of the allostatic load measure and age for 7,935 women (born before 1951) with an age eligibility threshold at age 60. The predicted values are obtained from the regression of an indicator for the eligibility age, a first-degree polynomial of the age variable centered at the state pension eligibility age (60 years old), and regression controls. Regression controls include governmental office region, marital status, total household wealth, amount of state pension, level of education, retirement status, size of the household, having experienced stressful episodes, number of comorbidities, two cognition controls (date and number of words) and whether the respondent has difficulty walking 100 yards and wave.

Figure 3.3 Predicted values of the allostatic load metric for men who reach the eligibility age at 65 years old and live in households with wealth higher than £35,000



Note: Predicted values of the allostatic load measure and age for 7,765 men with an age eligibility threshold at age 65. The predicted values are obtained from the regression of an indicator for the eligibility age, a first-degree polynomial of the age variable centered at the state pension eligibility age (65 years old), and regression controls. Regression controls include governmental office region, marital status, total household wealth, amount of state pension, level of education, retirement status, size of the household, having experienced stressful episodes, number of comorbidities, two cognition controls (date and number of words) and whether the respondent has difficulty walking 100 yards and wave.

Figure 3.4 Predicted values of the allostatic load metric for men who reach the eligibility age at 65 years old and live in households with wealth lower than £35,000



Note: Predicted values of the allostatic load measure and age for 7,765 men with an age eligibility threshold at age 65. The predicted values are obtained from the regression of an indicator for the eligibility age, a first-degree polynomial of the age variable centered at the state pension eligibility age (65 years old), and regression controls. Regression controls include governmental office region, marital status, total household wealth, amount of state pension, level of education, retirement status, size of the household, having experienced stressful episodes, number of comorbidities, two cognition controls (date and number of words) and whether the respondent has difficulty walking 100 yards and wave.

Table 3.3 Impact of state pension eligibility on allostatic load for females

Dependent variable and model	Linear in age						Quadratic in age						Cubic in age					
	Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000		
	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*
Allostatic load																		
Individual eligible for state pension	0.11	0.09	0.21	0.07	0.10	0.49	-0.05	0.11	0.64	-0.05	0.12	0.66	-0.04	0.13	0.78	0.13	0.15	0.40
Mean allostatic load prior to eligibility to state pension	1.54			1.87			1.54			1.87			1.54			1.87		
Relative effect	7.2%			3.9%			-3.2%			-2.8%			-2.4%			6.8%		
Observations	3,694			4,241			3,694			4,241			3,694			4,241		

Note: Each column includes female participants born before 1951, aged 55 to 99 and displays the effect of being eligible for state pension (60 years old) on the allostatic load variable. The results are stratified by level of income. All regressions include an indicator for eligibility, and a first, second and third-degree polynomial of a variable for age centered at the age of 60. All regressions control for sex, governmental office region, marital status, total household wealth, amount of state pension, level of education, retirement status, size of the household, having experienced stressful episodes, number of comorbidities, two cognition controls (date and number of words) and whether the respondent has difficulty walking 100 yards. The total household wealth variable corresponds to liquid assets and it does not include property or other physical wealth (e.g. jewelry). The threshold of 35,000 corresponds to the median of the wealth variable in our data. Taylor linearized standard errors displayed.

*** Significant at the 1 percent level

** Significant at the 5 percent level

Table 3.4 Impact of state pension eligibility on allostatic load for males

Dependent variable and model	Linear in age						Quadratic in age						Cubic in age					
	Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000		
	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*
Allostatic load																		
Individual eligible for state pension	0.06	0.08	0.42	-0.24	0.12	0.05	0.02	0.09	0.85	-0.36	0.13	<0.01	0.01	0.09	0.88	-0.35	0.13	<0.01
Mean allostatic load prior to eligibility to state pension	1.74			2.01			1.74			2.01			1.74			2.01		
Relative effect	3.7%			-11.7%		**	1.0%			-17.7%		***	0.8%			-17.2%		***
Observations	4,629			3,136			4,629			3,136			4,629			3,136		

Note: Each column includes male participants aged 50 to 99 and displays the effect of being eligible for state pension (65 years old) on the allostatic load variable. The results are stratified by level of income. All regressions include an indicator for eligibility, and a first, second and third-degree polynomial of a variable for age centered at the age of 65. All regressions control for sex, governmental office region, marital status, total household wealth, amount of state pension, level of education, retirement status, size of the household, having experienced stressful episodes, number of comorbidities, two cognition controls (date and number of words) and whether the respondent has difficulty walking 100 yards. The total household wealth variable corresponds to liquid assets and it does not include property or other physical wealth (e.g. jewelry). The threshold of £35,000 corresponds to the median of the wealth variable in our data. Taylor linearized standard errors displayed.

*** Significant at the 1 percent level

** Significant at the 5 percent level

3.5.1 Effects of stress reduction

Our research suggests that the UK state pension might have an effect reducing the levels of allostatic load among English male seniors living in households with wealth lower than of £35,000**,** by a magnitude between 11% and 17% depending on the specification used. The impact of these changes in the allostatic load can be hard to grasp since it is not a widely used metric yet. However, prior studies might shed a light on the significance of these findings. Prior research has found that the differences in the average allostatic load levels in the United States between white and African Americans reach in average 0.45 (Geronimus et al. 2006) and 0.12 between white and US born citizens of Mexican origin (Peek et al. 2010). Our results show that the eligibility for the state pension decreases the allostatic load levels between 0.24 and 0.36 in males with less wealth; that is an equivalent of between 50% and 75% the effect found in previous research of ethnicity on the allostatic load. Other study (Schulz et al. 2012) performed in the US shows that residents living in neighborhoods with 20% of households below the poverty line experienced levels of allostatic load 0.2 higher than the average person living in neighborhoods with less than 20% of households below the poverty line. This could suggest that the reductions in allostatic load levels related to the eligibility for the state pension are equivalent or even larger to those experienced when neighborhood poverty is reduced.

Chronic stress as measured by the allostatic load could have important effects in decision-making processes. Previous research suggests that stress and particularly allostatic load affects specific cognitive functions such as performance in tasks and working memory (Diamond 2005; Evans and Schamberg 2009), positive responses to the environment (Lindfors, Lundberg, and Lundberg 2006) and functionality (Kado et al. 2005; Karlamangla et al. 2002; Seplaki et al. 2004).

Also, maladaptive stress coping strategies are found to be important in determining temporal consistency leading to a reduced capacity to act and poor decision-making processes (Aken and van Aken 1991), and potentially including financial decisions (Agarwal et al. 2007). Preventive behavior can also be affected by stress, as it will be discussed in chapter 4 of this dissertation[22]. Some economic literature has also cited this relationship including stress as a mediator of the relationship between education and health (Cutler and Lleras-Muney 2006).

Pensions are intended to smooth the consumption path of seniors as they enter retirement. Most of benefit analyses focus on the income effect of pensions, but they do not take into account non-pecuniary welfare gains from the pension program. This paper presents the effect of the state pension on chronic stress. These gains can actually have financial consequences, as chronic stress has been associated with increased chronic conditions and mortality.

3.5.2 Heterogeneity of the effects of stress reduction

Our results show that the state pension reduces the levels of allostatic load among male seniors living in households with less than £35,000. The heterogeneity in the effect across levels of wealth of the household can be explained by the fact that households with less wealth are more likely to rely on the income from the state pension and therefore, the pension is a source of stress relief. Regarding the differences across categories of sex, we believe these are caused by the heterogeneity in the response of the allostatic load measure to financial stress between men and women. Prior research has shown how the reactivity of the allostatic load reflects social constructions of gender roles (Goldman et al. 2004). If that is the case, it is plausible that in this

[22] The next chapter assess the effect of allostatic load on preventive behavior.

population women become less sensitive to financial stress as they might rely on male partners or other individuals in the house to manage the finances and also bear the burden of financial stress. Assuming this holds true, it is straightforward that female respondents would have a lower reactivity to the state pension (to the point in which it is not significant in our data). If this hypothesis were true, the reduced sensitivity to financial stress would not apply for females who live by themselves and who are not living with a partner. To test this hypothesis, we performed the same regression analysis selecting only women who reported living without a partner and who live alone at their household[23]. We found that the coefficient of the eligibility threshold became negative and significant for this subset of women, specifically for those living in households with wealth less than £35,000. We believe these results show that the allostatic load levels in females are less sensitive to financial stress, which would lead to lower reactivity to the eligibility to the state pension, mainly because of prevalent gender roles of who manages and bears the stress of the finances in the household. Naturally, this would not apply to females living by themselves, where we found that the eligibility of the program becomes strongly significant in reducing the levels of allostatic load. This supports the argument that the state pension program provides stress relief to those in higher need and that the welfare gains of the pension program in terms of stress reduction to vulnerable individuals need to be taken into account. Similar results, stronger in magnitude are found in males living alone. The results of these analyses are available from the corresponding author upon request.

[23] See full results in appendix 3.2

3.6 Robustness checks

RDD requires evaluating the potential effect that the functional form of the specification might have on the results. For this reason, all RDD models displayed in the tables include results with the first, second and third-order polynomial.

A crucial assumption of RDD is that there are no sample-related issues, or any other observable and unobservable characteristic that can induce non-smooth changes of the outcome at the identification threshold (in this case the state pension eligibility age). For this reason, we ensure that the sample sizes below and above the eligibility age were not driving our results (See appendix 3.3, which displays the distribution of observations by year of age and sex). We also we tested all variables for such a non-smooth change (McCrary 2008).

With the exception of the retirement variable, whose age profile was statistically significant, and the variable of reporting having experienced stressful episodes, which was marginally statistically significant, all observed variables; including the allostatic load metric and the control variables display smooth age profiles across the UK state pension eligibility threshold (see Table 3.1 and appendices 3.4 and 3.5).

Some individuals retire at the time they become eligible for the UK state pension. This introduces a potential bias to our estimation as the eligibility threshold might be capturing the effect of retirement rather than the eligibility for the UK state pension. For this reason, we carried out a robustness check removing the retirement variable from the estimation. In table 3.5 and 3.6, we display the results of this estimation.

Finally, because our data has a panel structure, there is a possibility that time-correlated errors reduce the standard errors of our analyses increasing the risk of type 1 error. For this reason we replicated the analyses using a Generalized Estimating Equations estimation (see appendix 3.6).

Table 3.5 Impact of state pension eligibility on allostatic load for females with no control for retirement

Dependent variable and model	Linear in age						Quadratic in age						Cubic in age					
	Wealth at least £35,000			**Wealth less than £35,000**			**Wealth at least £35,000**			**Wealth less than £35,000**			**Wealth at least £35,000**			**Wealth less than £35,000**		
	Effect	SE	***p***	Effect	SE	***p***	Effect	SE	***p***	Effect	SE	***p***	Effect	SE	***p***	Effect	SE	***p***
Allostatic load																		
Individual eligible for state pension	0.08	0.08	0.33	0.07	0.07	0.50	-0.08	0.10	0.43	-0.07	0.12	0.59	-0.04	0.13	0.74	0.12	0.15	0.41
Mean allostatic load prior to eligibility to state pension	1.54			1.87			1.54			1.87			1.54			1.87		
Relative effect	5.2%			3.5%			-5.3%			-3.5%			-2.7%			6.6%		
Observations	3,694			4,241			3,694			4,241			3,694			4,241		

Note: Each column includes female participants born before 1951, aged 55 to 99 and displays the effect of being eligible for state pension (60 years old) on the allostatic load variable. The results are stratified by level of income. All regressions include an indicator for eligibility, and a first, second and third-degree polynomial of a variable for age centered at the age of 60. All regressions control for sex, governmental office region, marital status, total household wealth, amount of state pension, level of education, retirement status, size of the household, having experienced stressful episodes, number of comorbidities, two cognition controls (date and number of words) and whether the respondent has difficulty walking 100 yards. The total household wealth variable corresponds to liquid assets and it does not include property or other physical wealth (e.g. jewelry). The threshold of 35,000 corresponds to the median of the wealth variable in our data. Taylor linearized standard errors displayed.

*** Significant at the 1 percent level

** Significant at the 5 percent level

Table 3.6 Impact of state pension eligibility on allostatic load for males with no control for retirement

Dependent variable and model	Linear in age						Quadratic in age						Cubic in age					
	Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000		
	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*	Effect	SE	*p*
Allostatic load																		
Individual eligible for state pension	0.03	0.08	0.72	-0.07	0.11	0.52	0.00	0.09	0.99	-0.22	0.13	0.09	-0.01	0.09	0.92	-0.21	0.13	0.10
Mean allostatic load prior to eligibility to state pension	1.74			2.01			1.74			2.01			1.74			2.01		
Relative effect	1.6%			-3.5%			0.0%			-10.8%			-0.5%			-10.4%		
Observations	4,629			3,136			4,629			3,136			4,629			3,136		

Note: Each column includes male participants aged 55 to 99 and displays the effect of being eligible for state pension (65 years old) on the allostatic load variable. The results are stratified by level of income. All regressions include an indicator for eligibility, and a first, second and third-degree polynomial of a variable for age centered at the age of 65. All regressions control for sex, governmental office region, marital status, total household wealth, amount of state pension, level of education, retirement status, size of the household, having experienced stressful episodes, number of comorbidities, two cognition controls (date and number of words) and whether the respondent has difficulty walking 100 yards. The total household wealth variable corresponds to liquid assets and it does not include property or other physical wealth (e.g. jewelry). The threshold of 35,000 corresponds to the median of the wealth variable in our data. Taylor linearized standard errors displayed.

*** Significant at the 1 percent level

** Significant at the 5 percent level

We found that the effect sizes became less strong when not controlling for the retirement variable (Table 3.5 and 3.6). This is consistent with our finding that the average allostatic load, all other factors held constant, is positively correlated with retirement[24]. This finding leads us to conclude that even when retirement entails a potential source of endogeneity, as some people retire simultaneously to becoming recipients of the UK state pension, the effect of retirement on allostatic load is positive. This implies that our results on the effect of the UK state pension on the allostatic load are at most underestimated.

Given that the age profile of the variable of stressful episodes was marginally significant (see table 3.1), we also tested the effect of this variable in the estimations, finding no significant changes. The results of this analysis are available from the corresponding author upon request.

Another source of endogeneity comes from the National Insurance Contributions, which can be endogenously correlated to the allostatic load measure. For example, individuals that contribute for longer time to the National Insurance, or those who enrolled in S2P might have lower discount rates and have stronger preferences for a smooth utility function (Ellis and Del Giudice 2014). We cannot observe the extent to which these people optimized their National Insurance Contributions to smooth their consumption path; however, we can observe the resulting amount of state pension contribution[25], which constitutes a proxy of that type of precautionary behavior. We included in our estimations the amount of the state pension as a control variable to account for this effect.

[24] The coefficient, standard error and p-value of a linear regression of the allostatic load on retirement controlling for all other variables is displayed in appendix 3.4.

[25] The average UK state pension in our sample is £5,863. This includes both the basic (compulsory) state pension and the State Second Pension (S2P), which is a voluntary program in addition to the basic state pension.

We stratified all individuals by level of household wealth at the median of our variable of household wealth (£35,000)[26]. Our household wealth level was calculated similarly to prior studies using this survey (Hamer, de Oliveira, and Demakakos 2014; Marmot et al. 2003). However, we only included liquid assets and our metric does not include property or other physical wealth (e.g. jewelry). This was done in order to better approach a measure of wealth to a permanent income measure (Friedman 1957) and to reduce the risk for bias in the reporting of the value of physical capital.

3.7 Discussion

We took advantage of the eligibility threshold for receiving the state pension in England to explore, using a regression discontinuity design, the effect of the state pension on the levels of allostatic load, a proxy metric for stress. We used data from a longitudinal survey (ELSA) conducted in England between 2002 and 2013 and took advantage of the exogenous age-based rule assignment of individuals around the eligibility threshold for the UK state pension to measure the extent to which the eligibility to the social program reduces the levels of allostatic load, a proxy for stress. Our results suggest that there is a relationship between the eligibility for the state pension and a reduction of the allostatic load levels between 11% and 17% for males living in households with wealth lower than £35,000. In the case of female respondents, we found that this effect was found among those who live alone and reported not living with a partner. These results are robust to changes in the functional form to different non-linear specifications of the age variable, and when

[26] We conducted sensitivity analyses on the effect of the state pension establishing the threshold at £30,000 and £40,000, obtaining similar results.

considering other factors that could endogenously affect the relationship between the UK state pension and the allostatic load metric.

The magnitude of the effect of the state pension in the allostatic load seems equivalent to that experienced by moving out of a high poverty neighborhood in the US. Beyond these effects, reductions in the allostatic load metric might also lead to better cognitive performance, including working memory, functionality, and better decision-making processes. Also better health through preventive behavior, medication adherence and improved disease management are potential effects from reducing the allostatic load levels.

This study complements prior research on the extent to which social programs might yield welfare gains that are not traditionally measured in common cost-benefit evaluations. This is done by directly measuring the changes in a proxy variable for stress that assesses the physiological effects of chronic stress and its change after the eligibility threshold for the state pension. Consequently, this study is the first we are aware of that addresses the reduction of allostatic load as a proxy of stress, related to the eligibility of a social program.

These results are intended to contribute to the growing discussion on the unmeasured effects of social programs, especially in a time where social security in all countries is facing increasing sustainability risks triggered by a longer life expectancy and a narrowing population pyramid base. The very same UK state pension system is facing important changes that have led the parliament to extend the eligibility age to 67 years for both men and women by 2028.

This research sheds some light into a potential alternative policy approach. We observe that whereas becoming eligible for the UK state pension is associated with a significant reduction in allostatic levels for seniors with lower household wealth, those living in wealthier households did not experience a significant change. This suggests that the UK state pension is particularly relevant for seniors living in less affluent households and in more vulnerable conditions. Potential changes to the state pension program should consider that the burden of modifying pension schemes is larger among those living in precisely more vulnerable households. We believe the results of this research can motivate further studies evaluating the effects on the allostatic load measure of other social programs for seniors that provide cash transfers.

Finally this research also demonstrates the complexity and diverse dimensions in which social programs can have impacts (Peters 2014; Paina and Peters 2011). This is important because health can be affected in many ways from programs that are not directly related to the health sector, and circumscribing the role of the health systems to only those functions in which the health sector has a direct effect, might undermine those efforts. We offer an extra-sectorial perspective using population-level data on how the design of such reforms could remain targeting the most vulnerable segment of the population, while remaining sustainable.

This study assesses individuals captured in a longitudinal nationally representative survey of the United Kingdom. However, given the panel nature of the survey, we ended up selecting healthier individuals with likely lower levels of stress. Consequently, it is possible that our effect sizes are biased downwards. The research design selected is comprised by a RDD because the eligibility age of the UK state pension comprises a unique opportunity to count with a quasi-random design in which there should not be expected differences in the neighborhood of the threshold for other reasons that becoming eligible for the state pension. Finally, the economic literature in RDD has proposed newer techniques such as kernel estimation, constituting less traditional empirical strategies to create RDD designs. We did not use this last technique because we believe that given the increasing slope of the allostatic load over the lifetime, a kernel estimation would increase the risk of estimation bias given its poor asymptotic properties (Van Der Klaauw 2008).

Appendix 3.1

Linear regression of the eligibility threshold on the allostatic load measure

Allostatic load	Linear in age			Quadratic in age			Cubic in age		
	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*
Eligibility threshold	0.02	0.04	0.69	-0.05	0.05	0.34	-0.04	0.05	0.42
Age (centered)	-0.01	0.00	<0.01	0.00	0.00	0.22	-0.01	0.00	0.19
Age (centered)^2				0.00	0.00	<0.01	0.00	0.00	0.53
Age (centered)^3							0.00	0.00	<0.01
Sex	0.02	0.03	0.59	0.03	0.03	0.37	0.02	0.03	0.49
North-East	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
North-West	0.03	0.06	0.55	0.04	0.06	0.54	0.04	0.06	0.54
Yorkshire and the Humber	0.08	0.06	0.18	0.08	0.06	0.17	0.08	0.06	0.17
East Midlands	0.06	0.06	0.29	0.06	0.06	0.29	0.06	0.06	0.30
West Midlands	0.09	0.06	0.15	0.09	0.06	0.14	0.09	0.06	0.14
East of England	0.06	0.06	0.32	0.06	0.06	0.31	0.06	0.06	0.30
London	-0.01	0.06	0.93	0.00	0.06	0.94	0.00	0.06	0.97
South-East	0.02	0.05	0.67	0.02	0.05	0.68	0.02	0.05	0.66
South-West	0.08	0.06	0.18	0.08	0.06	0.18	0.08	0.06	0.18
Marital Status (REF: Living without a partner)	-0.08	0.03	0.01	-0.09	0.03	<0.01	-0.09	0.03	<0.01
Belonging to a household with more than 35,000	-0.16	0.03	<0.01	-0.16	0.03	<0.01	-0.16	0.03	<0.01
Amount of state pension	0.00	0.00	0.20	0.00	0.00	0.22	0.00	0.00	0.23

Results of the OLS regression of the eligibility threshold and different control characteristics on the allostatic load measure. The models include men aged 50 to 99 and women aged 53 to 99. Each one of the three sets of columns represents one linear regression with a different specification of the age variable. All categories of wealth and sex are included. These analyses are not stratified by level of wealth and sex.

Appendix 3.1 (cont.)

Linear regression of the eligibility threshold on the allostatic load measure (cont.)

Allostatic load	Linear in age			Quadratic in age			Cubic in age		
	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*
Education									
No qualification/other	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Foreign	-0.13	0.05	0.01	-0.13	0.05	0.01	-0.13	0.05	0.01
NVQ1	-0.10	0.06	0.12	-0.10	0.06	0.10	-0.10	0.06	0.11
NVQ2	-0.17	0.04	<0.01	-0.17	0.04	<0.01	-0.17	0.04	<0.01
NVQ3	-0.18	0.05	<0.01	-0.18	0.05	<0.01	-0.18	0.05	<0.01
NVQ4	-0.21	0.04	<0.01	-0.21	0.04	<0.01	-0.21	0.04	<0.01
NVQ5	-0.42	0.04	<0.01	-0.41	0.04	<0.01	-0.41	0.04	<0.01
Retired	0.06	0.03	0.05	0.05	0.03	0.12	0.05	0.03	0.12
Size of the household	-0.01	0.02	0.64	0.00	0.02	0.82	-0.01	0.02	0.70
Stressful episodes	0.11	0.03	<0.01	0.10	0.03	<0.01	0.10	0.03	<0.01
Number of comorbidities	0.14	0.01	<0.01	0.14	0.01	<0.01	0.14	0.01	<0.01
Cognitive test (Word recall)	-0.02	0.03	0.56	-0.02	0.03	0.55	-0.02	0.03	0.54
Cognitive test (date recall)	-0.01	0.00	0.14	-0.01	0.00	0.12	-0.01	0.00	0.14
Difficulty walking 100 yards	0.46	0.05	<0.01	0.47	0.05	<0.01	0.48	0.05	<0.01
Wave	-0.05	0.01	<0.01	-0.05	0.01	<0.01	-0.05	0.01	<0.01
Constant	2.16	0.13	<0.01	2.22	0.13	<0.01	2.19	0.13	<0.01
Obs		15,700			15,700			15,700	
R-Squared		0.05			0.05			0.05	
F		27.52			26.81			26.15	

Results of the OLS regression of the eligibility threshold and different control characteristics on the allostatic load measure. The models include men aged 50 to 99 and women aged 53 to 99. Each one of the three sets of columns represents one linear regression with a different specification of the age variable. All categories of wealth and sex are included. These analyses are not stratified by level of wealth and sex.

Appendix 3.2

Linear regression of the eligibility threshold on the allostatic load measure among women living with no partner and not reporting any other household member

Amount of state pension	Linear in age						Quadratic in age						Cubic in age					
	Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000		
	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*
Eligibility threshold	0.50	0.28	0.08	-0.48	0.25	0.05	0.36	0.32	0.26	-0.70	0.28	0.01	0.15	0.39	0.70	-0.28	0.34	0.42
Age (centered)	-0.02	0.01	0.02	-0.01	0.01	0.02	0.00	0.02	0.94	0.02	0.02	0.33	0.04	0.04	0.41	-0.05	0.03	0.16
Age (centered)^2							0.00	0.00	0.34	0.00	0.00	0.04	0.00	0.00	0.24	0.00	0.00	0.08
Age (centered)^3													0.00	0.00	0.31	0.00	0.00	0.02
North-East	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
North-West	0.13	0.31	0.67	-0.01	0.17	0.93	0.14	0.31	0.66	-0.02	0.17	0.91	0.12	0.31	0.69	0.00	0.17	0.99
Yorkshire and the Humber	0.41	0.32	0.20	0.13	0.19	0.49	0.41	0.32	0.19	0.13	0.19	0.49	0.41	0.32	0.20	0.13	0.19	0.49
East Midlands	0.24	0.33	0.47	0.05	0.19	0.78	0.25	0.34	0.45	0.05	0.19	0.81	0.25	0.34	0.46	0.07	0.19	0.73
West Midlands	-0.14	0.32	0.67	0.26	0.19	0.17	-0.13	0.32	0.68	0.26	0.19	0.16	-0.12	0.32	0.71	0.28	0.19	0.14
East of England	0.21	0.32	0.50	0.08	0.19	0.66	0.22	0.32	0.49	0.09	0.19	0.64	0.21	0.32	0.51	0.10	0.19	0.58
London	0.50	0.33	0.12	0.05	0.20	0.79	0.51	0.33	0.12	0.06	0.20	0.76	0.51	0.33	0.12	0.08	0.20	0.70
South-East	0.10	0.30	0.73	-0.04	0.17	0.81	0.11	0.30	0.72	-0.04	0.17	0.80	0.10	0.30	0.73	-0.03	0.17	0.88
South-West	0.38	0.31	0.23	0.05	0.18	0.77	0.38	0.31	0.22	0.06	0.18	0.75	0.37	0.31	0.23	0.06	0.18	0.75
Amount of state pension	0.00	0.00	0.95	0.00	0.00	<0.01	0.00	0.00	0.97	0.00	0.00	<0.01	0.00	0.00	0.99	0.00	0.00	<0.01

Results of the OLS regression of the eligibility threshold and different control characteristics on the allostatic load measure for women living alone and reporting not having a partner. The datasets includes women aged 53 to 99. Each one of the three sets of columns represents one linear regression with a different specification of the age variable.

Appendix 3.2 (cont.)

Linear regression of the eligibility threshold on the allostatic load measure among women living with no partner and not reporting any other household member (cont.)

Amount of state pension	Linear in age						Quadratic in age						Cubic in age					
	Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000		
	Coeff	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***
Retired	0.14	0.16	0.41	0.02	0.13	0.90	0.09	0.17	0.57	-0.03	0.13	0.81	0.08	0.17	0.65	-0.01	0.13	0.93
Education																		
No qualification	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Foreign	-0.20	0.21	0.33	-0.18	0.13	0.18	-0.19	0.21	0.36	-0.18	0.13	0.17	-0.19	0.21	0.36	-0.19	0.13	0.15
NVQ1	0.61	0.67	0.36	-0.02	0.30	0.94	0.62	0.67	0.36	-0.03	0.30	0.92	0.62	0.67	0.36	-0.05	0.30	0.88
NVQ2	-0.22	0.16	0.17	-0.11	0.12	0.37	-0.22	0.16	0.18	-0.10	0.12	0.38	-0.21	0.16	0.18	-0.11	0.12	0.36
NVQ3	-0.24	0.24	0.31	-0.32	0.19	0.10	-0.25	0.24	0.30	-0.32	0.19	0.09	-0.25	0.24	0.30	-0.32	0.19	0.09
NVQ4	-0.13	0.18	0.46	0.04	0.15	0.81	-0.12	0.18	0.50	0.04	0.15	0.80	-0.13	0.18	0.48	0.04	0.15	0.78
NVQ5	-0.09	0.20	0.64	-0.54	0.19	0.01	-0.08	0.20	0.71	-0.53	0.19	0.01	-0.07	0.20	0.71	-0.54	0.19	0.01
Stressful episodes	0.22	0.12	0.06	0.04	0.09	0.64	0.22	0.12	0.07	0.05	0.09	0.60	0.21	0.12	0.08	0.03	0.09	0.69
Number of comorbidities	0.18	0.04	<0.01	0.07	0.03	0.01	0.18	0.04	<0.01	0.07	0.03	0.02	0.18	0.04	<0.01	0.07	0.03	0.02

Results of the OLS regression of the eligibility threshold and different control characteristics on the allostatic load measure for women living alone and reporting not having a partner. The datasets includes women aged 53 to 99. Each one of the three sets of columns represents one linear regression with a different specification of the age variable.

Appendix 3.2 (cont.)

Linear regression of the eligibility threshold on the allostatic load measure among women living with no partner and not reporting any other household member (cont.)

Amount of state pension	Linear in age						Quadratic in age						Cubic in age					
	Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000		
	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*
Cognitive test (Word recall)	0.13	0.12	0.30	0.01	0.08	0.88	0.12	0.12	0.30	0.01	0.08	0.93	0.12	0.12	0.33	0.01	0.08	0.95
Cognitive test (date recall)	0.01	0.02	0.45	-0.01	0.01	0.47	0.01	0.02	0.44	-0.01	0.01	0.42	0.01	0.02	0.48	-0.01	0.01	0.53
Difficulty walking 100 yards	0.44	0.20	0.03	0.52	0.12	<0.01	0.45	0.20	0.02	0.53	0.12	<0.01	0.46	0.20	0.02	0.54	0.12	<0.01
Wave																		
Wave 2	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Wave 4	-0.07	0.17	0.67	-0.26	0.11	0.02	-0.08	0.17	0.66	-0.25	0.11	0.03	-0.09	0.17	0.59	-0.23	0.11	0.04
Wave 6	-0.42	0.16	0.01	-0.29	0.12	0.01	-0.43	0.16	0.01	-0.30	0.12	0.01	-0.44	0.16	0.01	-0.29	0.12	0.01

Results of the OLS regression of the eligibility threshold and different control characteristics on the allostatic load measure for women living alone and reporting not having a partner. The datasets includes women aged 53 to 99. Each one of the three sets of columns represents one linear regression with a different specification of the age variable.

Appendix 3.2 (cont.)

Linear regression of the eligibility threshold on the allostatic load measure among women living with no partner and not reporting any other household member (cont.)

Amount of state pension	Linear in age						Quadratic in age						Cubic in age					
	Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000			Wealth at least £35,000			Wealth less than £35,000		
	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*	Coeff	SE	*p*
Constant	0.51	0.64	0.43	2.36	0.40	<0.01	0.58	0.64	0.37	2.49	0.40	<0.01	0.76	0.67	0.25	2.21	0.43	<0.01
Obs		749			1,537			749			1,537			749			1,537	
R-Squared		0.07			0.04			0.07			0.05			0.07			0.04	
F		2.60			3.01			2.52			3.12			2.45			3.26	

Results of the OLS regression of the eligibility threshold and different control characteristics on the allostatic load measure for women living alone and reporting not having a partner. The datasets includes women aged 53 to 99. Each one of the three sets of columns represents one linear regression with a different specification of the age variable.

Appendix 3.3

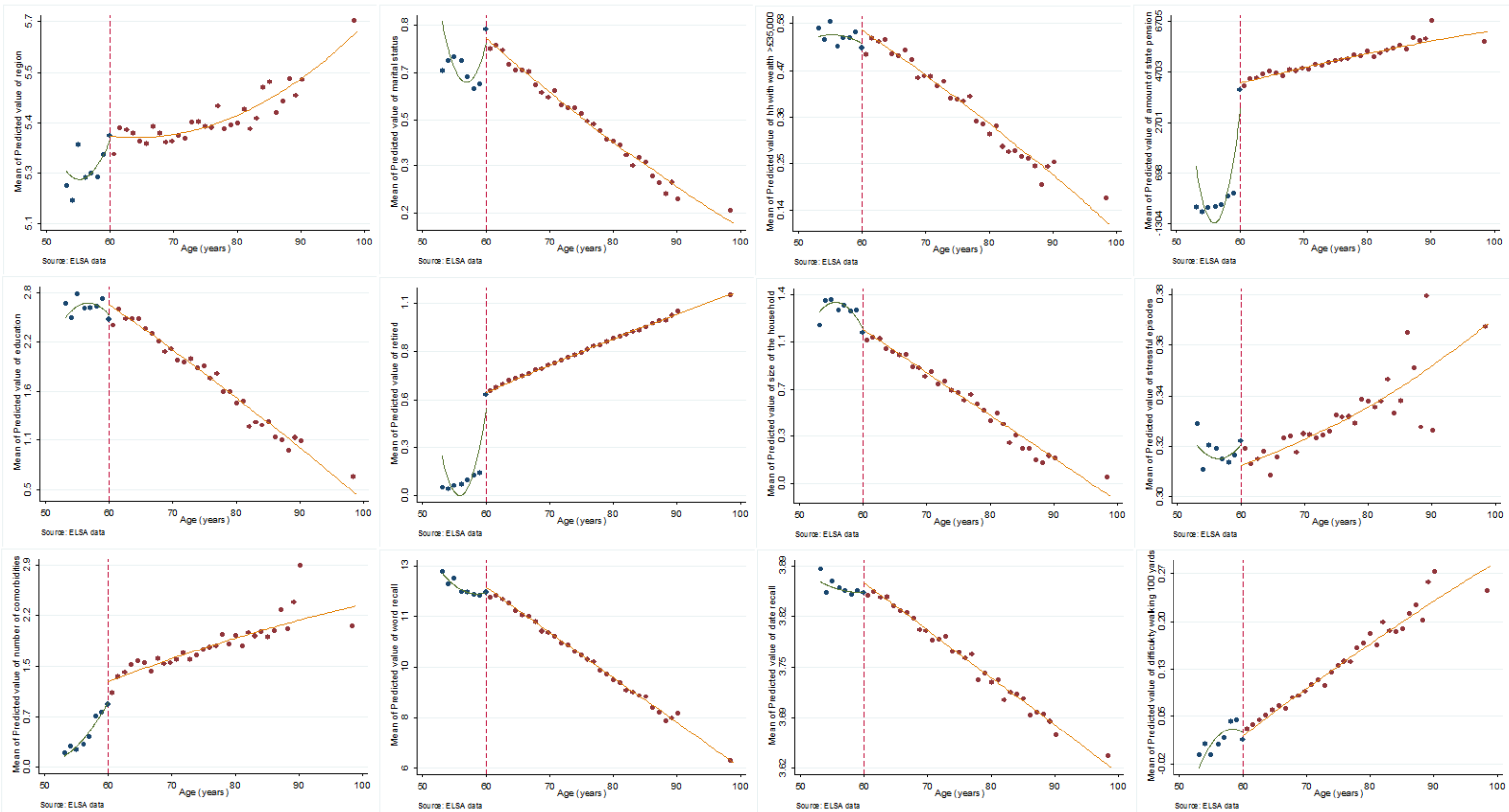
Distribution of respondents by age and sex

Age	Female	Male	Total
50	0	26	26
51	0	63	63
52	0	117	117
53	16	287	303
54	119	292	411
55	136	275	411
56	188	300	488
57	206	365	571
58	293	372	665
59	250	311	561
60	**338**	361	699
61	360	351	711
62	380	374	754
63	368	314	682
64	407	332	739
65	395	**342**	737
66	373	336	709
67	331	295	626
68	351	295	646
69	324	277	601
70	311	247	558
71	287	275	562
72	291	246	537
73	258	222	480
74	286	209	495
75	259	226	485
76	220	164	384
77	217	184	401
78	197	150	347
79	172	141	313
80	140	117	257
81	143	98	241
82	130	93	223
83	104	94	198
84	101	72	173
85	97	55	152
86	75	53	128
87	61	50	111
88	48	30	78
89	44	30	74
90 or more	124	68	192
Total	8,400	8,509	16,909

Note: The eligibility age for women is 60 years in our sample. For men, the eligibility age is 65.

Appendix 3.4

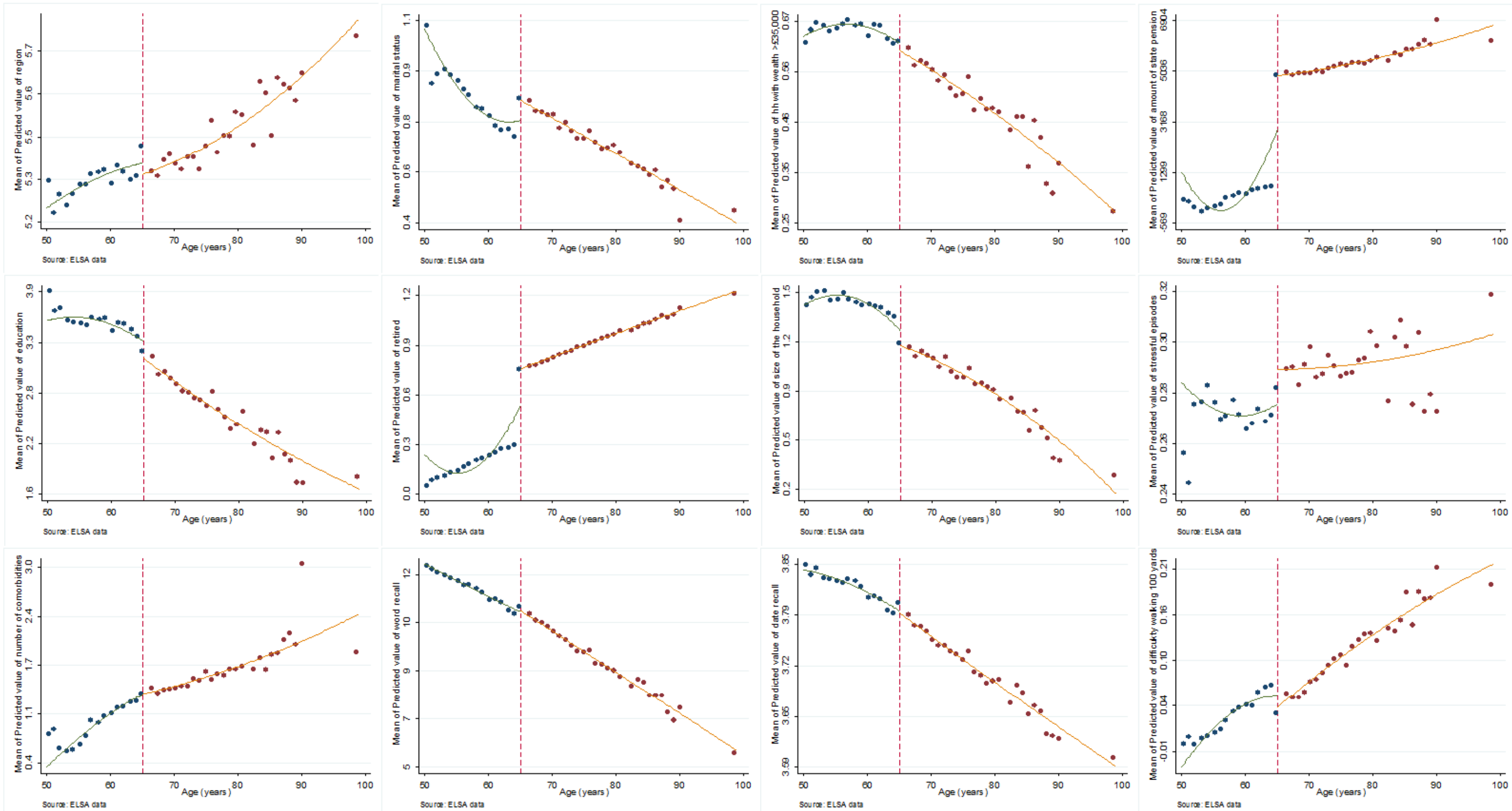
Smoothness test for the covariates in women. Predicted value of the regression of each covariate on the eligibility threshold



Predicted results of the regression of the independent variables on the eligibility threshold for state pension controlling for a dummy for age in linear form, all other covariates described elsewhere in the text and wave. No smoothness test was performed for the dependent variable, and the independent variables age and sex. The amount of state pension is GBP per year. Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis.

Appendix 3.5

Smoothness test for the covariates in men. Predicted value of the regression of each covariate on the eligibility threshold



Predicted results of the regression of the independent variables on the eligibility threshold for state pension controlling for a dummy for age in linear form, all other covariates described elsewhere in the text and wave. No smoothness test was performed for the dependent variable, and the independent variables age and sex. The amount of state pension is GBP per year. Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis.

Appendix 3.6

Regression using generalized estimating equations on the allostatic load measure by sex and category of wealth

Allostatic load	**Female**						**Male**					
	Wealth at least £35,000			**Wealth less than £35,000**			**Wealth at least £35,000**			**Wealth less than £35,000**		
	Coeff	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***
Eligibility threshold	-0.08	0.11	0.44	0.18	0.12	0.14	0.04	0.08	0.59	-0.19	0.11	0.09
Age (centered)	0.03	0.01	0.07	-0.01	0.01	0.50	-0.01	0.01	0.12	0.00	0.01	0.53
Age (centered)^2	0.00	0.00	0.20	0.00	0.00	0.37	0.00	0.00	0.15	0.00	0.00	0.02
Age (centered)^3	0.00	0.00	0.80	0.00	0.00	0.10	0.00	0.00	0.98	0.00	0.00	0.36
North-East	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
North-West	0.02	0.16	0.88	-0.10	0.13	0.46	0.10	0.14	0.46	0.19	0.15	0.20
Yorkshire and the Humber	0.15	0.16	0.36	0.05	0.13	0.69	0.08	0.14	0.59	0.05	0.15	0.73
East Midlands	0.00	0.16	0.98	-0.06	0.14	0.68	0.25	0.14	0.08	0.08	0.15	0.57
West Midlands	0.12	0.16	0.46	0.01	0.13	0.95	0.14	0.14	0.31	0.10	0.15	0.51
East of England	0.12	0.15	0.44	0.04	0.14	0.75	0.03	0.14	0.84	0.04	0.15	0.77
London	0.02	0.16	0.90	-0.03	0.14	0.85	0.03	0.15	0.82	0.02	0.16	0.89
South-East	-0.01	0.14	0.97	-0.11	0.13	0.41	0.08	0.13	0.56	0.06	0.14	0.67
South-West	0.04	0.15	0.79	-0.04	0.14	0.75	0.18	0.14	0.20	0.06	0.15	0.68
Marital Status (REF: Living without a partner)	-0.12	0.07	0.12	0.01	0.06	0.90	-0.17	0.07	0.01	-0.12	0.07	0.10
Amount of state pension	0.00	0.00	0.71	0.00	0.00	0.32	0.00	0.00	0.63	0.00	0.00	0.18

Results of the Generalized Estimating Equations regression of the eligibility threshold and different control characteristics on the allostatic load measure by wealth and sex. The analyses include men aged 50 to 99 and women aged 53 to 99.

Appendix 3.6 (cont.)

Regression using generalized estimating equations on the allostatic load measure by sex and category of wealth (cont.)

Allostatic load	**Female**						**Male**					
	Wealth at least £35,000			**Wealth less than £35,000**			**Wealth at least £35,000**			**Wealth less than £35,000**		
	Coeff	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***
Education												
No qualification/other	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Foreign	-0.12	0.11	0.27	-0.15	0.09	0.13	-0.13	0.17	0.43	-0.19	0.15	0.22
NVQ1	0.39	0.21	0.07	0.14	0.21	0.50	-0.16	0.13	0.23	-0.26	0.12	0.03
NVQ2	-0.17	0.09	0.04	-0.09	0.08	0.25	-0.17	0.09	0.06	-0.21	0.09	0.03
NVQ3	-0.17	0.14	0.22	-0.27	0.14	0.05	-0.17	0.10	0.10	-0.19	0.13	0.13
NVQ4	-0.17	0.10	0.08	-0.23	0.11	0.03	-0.16	0.09	0.08	-0.29	0.10	0.01
NVQ5	-0.38	0.10	<0.01	-0.54	0.13	<0.01	-0.39	0.09	<0.01	-0.58	0.12	<0.01
Retired	0.11	0.06	0.05	0.04	0.06	0.50	-0.08	0.06	0.15	0.20	0.08	0.01
Size of the household	0.07	0.04	0.13	-0.03	0.04	0.46	0.02	0.03	0.53	-0.03	0.03	0.38
Stressful episodes	0.20	0.07	<0.01	0.11	0.06	0.09	0.15	0.06	0.01	0.01	0.07	0.91
Number of comorbidities	0.11	0.02	<0.01	0.04	0.02	0.02	0.12	0.02	<0.01	0.06	0.02	<0.01
Cognitive test (Word recall)	0.03	0.06	0.63	0.05	0.05	0.30	-0.12	0.05	0.01	0.01	0.05	0.87
Cognitive test (date recall)	0.00	0.01	0.65	-0.01	0.01	0.24	-0.01	0.01	0.14	-0.01	0.01	0.25
Difficulty walking 100 yards	0.52	0.11	<0.01	0.37	0.08	<0.01	0.46	0.12	<0.01	0.17	0.09	0.05
Wave	-0.04	0.02	0.03	-0.03	0.02	0.13	-0.02	0.01	0.10	-0.03	0.02	0.14
Constant	1.56	0.28	<0.01	1.87	0.24	<0.01	2.50	0.24	<0.01	2.35	0.25	<0.01
Obs		3,693			4,241			4,627			3,136	

Results of the Generalized Estimating Equations regression of the eligibility threshold and different control characteristics on the allostatic load measure by wealth and sex. The analyses include men aged 50 to 99 and women aged 53 to 99.

4. Does chronic stress affect preventive behavior among seniors in England?

Abstract

Prior literature suggests that chronic stress among seniors can constitute a barrier to engage in preventive behavior. Low levels of prevention lead to worse health and potentially, higher mortality and use of high-cost health services. We empirically studied the effect of stress levels as measured through a composite metric of biomarkers on three different preventive behaviors among English seniors. Our identification approach relies on an instrumental variables analysis. We found that chronic stress, as measured with our allostatic load metric in a nationally-representative survey of English seniors (English Longitudinal Survey of Ageing), is likely to reduce the engagement in preventive behavior, specifically increasing smoking, and reducing the demand for the breast and bowel cancer screening programs.

4.1 Introduction

The effectiveness and "implementability" of large-scale preventive programs for seniors have proven to be challenging due to both mixed results in their effectiveness and the different populations and risk factors that these programs intend to target (Coberley, Rula, and Pope 2011).

Programs to improve health behavior in seniors are in need of creating health behavior strategies that are both effective at the population level and that also target individuals at a higher risk of developing disease (Spring, Moller, and Coons 2012). Consequently, in order to improve preventive behaviors at the population level while targeting higher risk populations, it is necessary to find common aspects that comprise barriers for people to engage on them. Chronic stress may be one of those factors. Prior literature has suggested a relationship between perceived stress and engaging in preventive behaviors (Barrington et al. 2012; Ng and Jeffery 2003). Describing the nature of that link, and therefore the role of stress as a potential mediating factor in the link between stress and disease is key. Stress might reduce the level of self-efficacy in seniors and consequently reduce their willingness to engage in preventive activities (Bandura 2010; Cherrington et al. 2011; Floyd, Prentice-Dunn, and Rogers 2000; Jayanti and Burns 1998). If seniors engage in less preventive activities, they become more likely to have chronic diseases, potentially increasing the utilization of highly cost medical services and reducing their longevity.

Chronic stress has become an important topic in recent years. For example in the US, 50% of Americans report having at least one significant stressful event in the past year (Robert Wood Johnson Foundation/Harvard School of Public Health 2014). In the United Kingdom, according to the Mental Health Foundation, 47% of adults feel stressed every day, and 59% report feeling more stressed now than 5 years ago (Mental Health Foundation 2013). In part, stress is financially driven. Thirty per cent of the population older than 45 in Britain report feeling stressed because of difficulties on making ends meet (Arber, Fenn, and Meadows 2014).

The literature highlights the high prevalence of stress and the hypothesis that chronic stress affects the likelihood of people to engage in preventive behaviors. This is especially important among seniors because they are particularly vulnerable to stressful conditions. Seniors face constant sources of chronic stress due to a higher likelihood of financial vulnerability as they move towards retirement, in addition to the emotional challenges of evolving changes in societal roles. Furthermore, some seniors can experience some level of cognitive decline, which reduces the ability to cope with stressful events (Rebok, Parisi, and Kueider 2014). As levels of chronic stress increase with age[27], seniors are also more vulnerable to the health, cognitive and emotional consequences of higher levels of stress, and it is for this reason that stress among seniors represents an important policy target.

This paper examines the effect that chronic stress has on preventive behavior among seniors in England, and contributes to the existing research by providing an understanding of the extent to which chronic stress might constitute a barrier for preventive behavior. These results offer an insight to these barriers and therefore, facilitate the creation of solutions that affect both the general population of seniors as well as those with higher risk of disease. We did not find prior empirical studies using econometric strategies to describe the effect that chronic stress has on preventive behavior at the population level.

We measured chronic stress levels by using a set of biomarkers available in the data using a metric called allostatic load. This metric has been extensively used in neuropsychology and it is being increasingly used in social sciences and social epidemiology (Crimmins et al. 2003; Gersten, Dow, and Rosero-Bixby 2010; Juster, McEwen, and Lupien 2010; Bruce S. McEwen 2000; Rosero-Bixby and Dow 2009; T. E. Seeman, Singer, et al. 1997). The allostatic load metric is an empirical tool that signals the neuroendocrine response to stress in five different dimensions (i.e. cardiovascular, glucocorticoid, sympathetic, hypothalamic-pituitary-adrenal axis and immune activity) (Read and Grundy 2012).

Measuring how chronic stress affects preventive behavior entails two methodological challenges. First, chronic stress is product of both the stressor itself (or external factors, either environmental

[27] This is shown in chapter 2 of this dissertation

or developmental) and the behavioral individual response to the stressor (Bruce S. McEwen 2000) and therefore, self-reported levels of stress are often not reliable as coping strategies can affect how stress is perceived and reported (Kirschbaum et al. 1999; Rosero-Bixby and Dow 2009). In the economic literature, stress has been measured through self-report (Rosero-Bixby and Dow 2009) or through indirect measures as proxies for stress such as the exposure to war (Costa and Kahn 2010). However, in the neuropsychological literature an alternative measure for stress known as allostatic load has been used for the last twenty years (T. E. Seeman, McEwen, et al. 1997). The allostatic load is an index that counts the number of abnormal physiological biomarkers that capture the physiological response to chronic stress.

The second challenge is the endogeneity. Our working hypothesis is that chronic stress, which is proxied by the allostatic load measure, reduces preventive behavior. However, some of the biomarkers used to build the allostatic load metric are a manifestation of the disease itself (e.g. blood pressure), which in turn, is generally caused by reduced preventive behavior and can either decrease or increase preventive behavior depending on each individual's response and the specific health condition. As a consequence, our identification strategy aims at instrumenting the allostatic load variable to measure the effect of chronic stress on preventive behavior by controlling for endogenous factors that affect both, such as comorbidities. We conducted robustness checks to confirm the validity of our instruments.

In this paper, we estimate the effect that the allostatic load metric has on preventive behavior among seniors in England. Our identification strategy relies on an instrumental variables design that assesses the effect of chronic stress, as measured by the allostatic load metric, on preventive behavior. We captured the exogenous variation in stress by using two instrumental variables, 1) whether the person perceives difficulty managing her finances, and 2) whether the respondent had a highly stressful event in her lifetime. The first instrument is intended to capture the respondent's current perception of her ability to manage her own finances, which are a common source of stress as discussed before (Mental Health Foundation 2013). The second variable captures whether the respondent has had any highly stressful episodes during her life, which is also related to higher allostatic load levels. This is a similar approach that has been used in previous research on stress in economics (Costa and Kahn 2010).

The instrumental variables technique requires that the instruments are strongly correlated with the endogenous variable (in our case, the allostatic load measure); but that they have no relationship with the dependent variable (preventive behavior), and that the only link between the instrument and the outcome is through chronic stress. Prior evidence shows that the instruments are related to stress as described above. Both instruments could arguably be related to preventive behavior through risk-aversion; however, stress has been found to modulate risk-taking behavior (Porcelli and Delgado 2009; Mann 1992; Trimpop 1994) . This implies that changes in risk-taking behavior that affect both preventive behavior and financial concerns, would be the actual behavioral signal of stress, our mediating variable.

By taking advantage of an instrumental variable design, this paper attempts to test the hypothesis that chronic stress, measured with the allostatic load metric, has a potential causal effect on preventive behavior. This design is possible thanks to the high-quality data obtained from the English Longitudinal Survey for Ageing (ELSA) which is comprised by a panel of individuals followed between 2002 and 2013 across six waves, three of them (2005, 2009 and 2013) including biomarker measurements (English Longitudinal Survey of Ageing 2001; Marmot et al. 2003;

Phillips et al. 2012). In this research, we only use individuals and waves in which biomarkers were taken with the aim of assessing their levels of allostatic load.

Identifying stress as a potential causal factor that prevents seniors from engaging in preventive activities provides policy-makers and clinicians with a tool to identify individuals at risk of not engaging in preventive activities. If these individuals are invited to join, for example, more intensive programs, its uptake could be potentially increased. Second, population-level programs that reduce stress levels, such as the UK state pension (see chapter 3 of this dissertation)[28] may generate a previously unobserved value to the society by increasing adherence to preventive behavior, and further reducing direct and indirect costs attributable to poor health behaviors down the line.

In this research, we find that the increase in one additional unit of the allostatic load metric was related to a reduction of 29% and 36% in the demand for breast cancer and bowel cancer screening programs, and an increase of at least 318% in the average consumption of tobacco.

Our research contributes to the existing literature by suggesting that chronic stress might affect preventive behavior.

4.2 The Cutler and Lleras framework on how education affects health and an expansion on the potential effect of stress.

Cutler and Lleras-Muney examine the relationship between education and health, confirming with empirical data the existence of a positive gradient in its relationship (Cutler and Lleras-Muney

[28] The aim 2 of this dissertation assesses the effect of the UK state pension on allostatic load levels.

2006). They suggest that beyond income, occupation, and health care, other factors associated to both education and health might be confounding this relationship. These other factors include time discounting and risk preferences, social status, social networks, technology and information, and cognitive skills. The latter is of relevance to this work because it might constitute the dimension in which stress plays a role on preventive behavior. In this framework, they show how education has proven to have an impact on the uptake of preventive behavior. However, a less known aspect is about the ability of individuals to properly process information, beyond formal education. The authors discuss how education might improve the ability of individuals to have critical judgement, have better decision-making skills, reduce cognitive biases, or improve the way they learn. All these conditions apply when considering the effect that education has over the lifetime. Take for example preventive behavior. Education is likely to be a time-invariant factor, and therefore, education is exogenous as the choices about education were usually taken decades before. However, people might experience changes in their ability to take care of their health over the lifetime. This variability is hence not captured by the time-invariant effect of education. That is where stress might play a role in changing the ability of those individuals to properly process information and take decisions on their health over time, independently of their education level.

Therefore, changes in cognitive skills that prevent the performance of preventive behavior can be caused by non-education related factors that affect the ability to process information. Even though seniors often experience losses in cognitive skills related to age, other factors such as chronic stress have shown to affect cognitive skills and decision-making processes (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2002). This research aims to capture the effect of stress on preventive behavior among seniors in England

4.3 Data and study sample

We are using data from the English Longitudinal Study of Aging (ELSA). ELSA is a 6-wave nationally representative longitudinal survey of the non-institutionalized population above 50 in England jointly conducted by the University College of London, the Institute for Fiscal Studies, and the National Center for Social Research based on the Health Survey for England (Marmot et al. 2003; Phillips et al. 2012). We are using this survey because it includes biomarker information for the individuals assessed in waves 2, 4 and 6 (2005, 2009 and 2013), which allows us to create an allostatic load metric as a proxy for chronic stress.

The initial ELSA sampling framework was based on all the households that responded the Health Survey for England (HSE) of 1998, 1999, or 2001 with a total of 23,132 households interviewed. HSE is a cross-sectional nationally representative survey of the non-institutionalized population conducted every two years to assess the health status of the population of England. The HSE population involves a multistage probability sampling approach based on postal codes and households (English Longitudinal Survey of Ageing 2001; Rachel Craig and Jennifer 2014). Of all the households that responded these three HSE surveys, all households with at least one eligible member were defined as eligible households in the ELSA survey. An eligible member was defined as anyone in the household born before February 29th, 1952 (17,744 individuals) and who agreed to be re-contacted (11,391 individuals). Younger partners of eligible household members were also included in the survey, but they are not included in our study since they are not being taken samples for assessment of biomarkers. Potential biases are introduced by this condition, especially the possibility of self-selection by capturing healthier individuals who are more likely and more willing to be re-contacted.

All eligible individuals (n=11,391 at wave 1) were contacted and followed up during six biennial waves when possible. Of the initial 11,391 eligible individuals at wave 1, 8,781 (82%) were followed-up during the second wave, when the first round of biomarkers samples were taken. Subsequent cohorts of individuals ("refreshment samples") from the HSE were added in 2007 at wave 3 (n=1,276), in 2009 at wave 4 (n=1,219) and in 2013 at wave 6 (n=2,253) in order to maintain a representative sample of the population older than 50 given the attrition of the survey.

The ELSA survey included biometric and anthropometric measurements at wave 2, 4 and 6. In each of the waves, all the participants who did not have an exclusion criterion for performing biometric and/or anthropometric measures were invited to schedule a nurse visit to be part of the "nurse subsample", where all biometric and anthropometric measurements were taken. The exclusion criteria were 1) Not providing written consent for the measurements; 2) The participant was on anticoagulant medication or had a clotting or bleeding disorder (for blood samples). In addition to these exclusion criteria, for blood samples requiring fasting, they were not taken on respondents who 1) were over 80 years old; 2) seemed frail or ever had a seizure; or 3) the nurse had concerns about asking them to fast for any other specific health concern. Fasting was defined as having had any food or drink except water five hours prior to the blood test (de Oliveira et al. 2008). Once again, the bias introduced by the eligibility criteria for the biometric and anthropometric measurements to enroll healthier subjects will be assessed in this study.

This research study included all the individuals present in waves 2, 4, or 6, including those included in the refreshment samples that were willing and fit enough to provide biomarker samples. Of the 24,187 individuals present in the three waves, 18,828 had blood samples and anthropometric measurements taken, and therefore these individuals comprise the study sample used in this research study (6,215 for wave 2; 6,433 for wave 4; and 6,180 for wave 6). This is the sample of study

More information on the ELSA survey can be found in the internal ELSA documentation (Marmot et al. 2003; Phillips et al. 2012) or in the ELSA website at www.elsa-project.ac.uk . Specific weights for the subsample of individuals with biomarkers taken are available in the dataset and used accordingly. In table 2.1, we are displaying the descriptive statistics of the allostatic load and the independent variables. Table 2.1 also displays the differences (and the p-values) between the respondents with and without biomarker samples.

The ELSA survey is publicly available through online registration and acceptance of the terms and conditions (Erens and Primatesta 1999; Prior et al. 2003; Taylor, Conway, and Lessof 2003). The Institutional Review Board (IRB) of the Johns Hopkins School of Public Health determined this research project and the data proposed to be used as "not human subjects research" on December 3rd, 2014 and therefore it does not require IRB oversight.

4.3.1 Sample selection bias

Given that only seniors who were fit enough to undergo the biomarker tests and who agreed to be tested are included in this sample, we are likely using a subsample of younger, healthier, wealthier, more likely to be working, more likely to be living with a partner, and more educated. Table 4.1 shows the differences between the study sample and the full sample with all the individuals included in the ELSA survey across the three waves (including those who do not have biomarker measurements). The study sample includes 78% of the full sample. This type of sample selection bias is inherent to conducting research using biomarkers in senior populations. The selection bias in our study sample is likely to bias downwards the effects found during this study, as the population we are observing is generally more affluent and healthier than the general population. Any relationship of the independent variables with the allostatic load measure is therefore likely to be equal or smaller than what would have been seen in a less healthy population (T. E. Seeman, Singer, et al. 1997; Teresa E. Seeman et al. 2001).

Table 4.1 Descriptive statistics for the independent variables and the allostatic load measure

Variables	Wave 2		Wave 4		Wave 6		Full sample		
	n	%	n	%	n	%	*n*	%	*p*
Allostatic load									
0	1,511	24.3	1,510	23.5	1,471	23.8	6,779	28.0	N/A
1-2	2,825	45.5	2,952	45.9	2,800	45.3	10,982	45.4	
3-4	1,432	23.0	1,551	24.1	1,499	24.3	5,129	21.2	
More than 4	447	7.2	420	6.5	410	6.6	1,303	5.4	
Age									
50-59	1,976	31.8	1,876	29.2	1,444	23.4	6,692	27.7	<0.01
60-69	2,129	34.3	2,487	38.7	2,527	40.9	8,759	48.2	
70-79	1,456	23.4	1,498	23.3	1,608	26.0	6,058	33.3	
80 or more	654	10.5	572	8.9	601	9.7	2,684	14.8	
Sex									
Male	2,829	45.5	2,910	45.2	2,770	44.8	10,888	45.0	0.27
Female	3,386	54.5	3,523	54.8	3,410	55.2	13,305	55.0	
Region									
North-East	424	6.8	407	6.3	372	6.0	1,537	6.4	0.83
North-West	802	12.9	701	10.9	694	11.2	2,777	11.5	
Yorkshire and the Humber	665	10.7	703	10.9	668	10.8	2,604	10.8	
East Midlands	605	9.7	640	9.9	674	10.9	2,562	10.6	
West Midlands	681	11.0	749	11.6	686	11.1	2,639	10.9	
East of England	743	12.0	810	12.6	768	12.4	3,050	12.6	
London	511	8.2	540	8.4	489	7.9	2,023	8.4	
South-East	1,046	16.8	1,125	17.5	1,070	17.3	4,121	17.0	
South-West	736	11.8	758	11.8	759	12.3	2,874	11.9	

Note: Each column includes participants aged 50 to 99 and displays the descriptive statistics of each of the independent variables for all individuals included in the study sample (n=18,828 respondents) by wave. The full sample column includes all 24,187 individuals in the survey and the p-value represents the results of a bivariate test depicting the differences between the full sample and the study sample. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. 1 Great Britain Pound (GBP) is equivalent to approximately 1.4 USD. The education variable has eight categories from the National Vocational Qualification of England: no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate). Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis.

Table 4.1 Descriptive statistics for the independent variables and the allostatic load measure (cont.)

Variables	Wave 2		Wave 4		Wave 6		Full sample		
	n	%	n	%	n	%	*n*	%	*p*
Marital status									
Living without partner	1,954	31.4	2,096	32.6	2,082	33.7	8,040	44.3	<0.01
Living with partner	4,260	68.6	4,334	67.4	4,095	66.3	16,144	88.9	
Size of the household									
0	1,423	22.9	1,375	21.4	1,332	21.6	5,459	22.6	
1	3,718	59.8	3,562	55.4	3,486	56.4	13,694	56.6	
2	736	11.8	873	13.6	803	13.0	3,047	12.6	0.09
3-4	307	4.9	563	8.8	519	8.4	1,821	7.5	
More than 4	31	0.5	60	0.9	40	0.6	172	0.7	
Retired									
Yes	3,257	52.4	3,660	59.2	3,175	59.2	13,538	56.0	<0.01
No	2,958	47.6	2,520	40.8	2,190	40.8	10,655	44.0	
Education level									
No qualification/other	2,322	37.7	1,993	31.3	1,594	28.8	7,862	43.3	
Foreign	513	8.3	420	6.6	345	6.2	1,650	9.1	
NVQ1	288	4.7	241	4.1	213	#REF!	981	5.4	
NVQ2	1,109	18.0	1,261	19.8	1,135	20.5	4,375	24.1	<0.01
NVQ3	411	6.7	502	7.9	458	8.3	1,700	9.4	
NVQ4	768	12.5	891	14.0	820	14.8	3,119	17.2	
NVQ5	754	12.2	1,058	16.6	972	17.6	3,459	19.0	

Note: Each column includes participants aged 50 to 99 and displays the descriptive statistics of each of the independent variables for all individuals included in the study sample (n=18,828 respondents) by wave. The full sample column includes all 24,187 individuals in the survey and the p-value represents the results of a bivariate test depicting the differences between the full sample and the study sample. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. 1 Great Britain Pound (GBP) is equivalent to approximately 1.4 USD. The education variable has eight categories from the National Vocational Qualification of England: no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate). Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis.

Table 4.1 Descriptive statistics for the independent variables and the allostatic load measure (cont.)

Variables	Wave 2		Wave 4		Wave 6		Full sample		
	n	%	n	%	n	%	*n*	%	*p*
Total household wealth (GBP)									
Less than 35,000	3,271	54.9	2,988	48.5	2,629	44.2	11,735	64.6	<0.01
35,000-60,000	686	11.5	713	11.6	674	11.3	2,602	14.3	
60,000-100,000	761	12.8	759	12.3	737	12.4	2,839	15.6	
More than 100,000	1,240	20.8	1,705	27.7	1,914	32.1	6,081	33.5	
Ever having a stressful episode									
Yes	1,919	30.9	1,851	28.8	1,583	25.6	6,821	28.2	<0.01
No	4,296	69.1	4,582	71.2	4,597	74.4	17,366	71.8	
Number of comorbidities									
0	4,226	68.0	1,725	26.8	1,371	22.2	8,907	49.0	
1-2	1,918	30.9	3,160	49.1	1,673	27.1	6,535	36.0	<0.01
More than 2	71	1.1	1,548	24.1	3,136	50.7	8,751	48.2	
Cognitive test (word recall)									
Less than 10	2,057	35.4	1,961	32.0	1,932	31.3	7,979	34.5	
10-15	3,444	59.3	3,670	59.9	3,727	60.3	13,540	58.5	<0.01
16-20	308	5.3	491	8.0	521	8.4	1,622	7.0	
Cognitive test (date recall)									
Less than 4	1,246	20.2	1,185	18.5	1,026	16.7	4,583	19.1	<0.01
4 (maximum)	4,919	79.8	5,224	81.5	5,117	83.3	19,427	80.9	

Note: Each column includes participants aged 50 to 99 and displays the descriptive statistics of each of the independent variables for all individuals included in the study sample (n=18,828 respondents) by wave. The full sample column includes all 24,187 individuals in the survey and the p-value represents the results of a bivariate test depicting the differences between the full sample and the study sample. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. No p-value is presented for the allostatic load variable as the study sample only included individuals with allostatic load measured. 1 Great Britain Pound (GBP) is equivalent to approximately 1.4 USD. The education variable has eight categories from the National Vocational Qualification of England: no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate). Comorbidities included in the number of comorbidities variable are: angina, myocardial infarction history, congestive failure, stroke history, lung disease, cancer, high blood pressure, diabetes, high cholesterol, and arthritis.

4.3.2 Outcome: preventive behaviors

We retrieved three different self-reported variables from the ELSA dataset that encompass prevention activities: (1) Tobacco use, measured as the number of cigarettes and/or roll-ups smoked per week. In the case of the roll-ups, as the survey only provides the number of ounces of tobacco consumed per week, we assumed each rollup would contain the equivalent of 50% of the tobacco content of a cigarette (GP Notebook 2016). Smoking prevalence in our data is around 10%, similar to what has been found in public reports (ASH - Action on Smoking and Health 2016). Despite the large number of current non-smokers, we decided to keep them in the analyses as former smokers might restart the smoking behavior over time. Two more outcomes, focusing on screening activities were also used; (2) Bowel cancer screening performed by the NHS Bowel Cancer Screening Programme (NHSBCSP) (NHS Bowel Cancer Screening Programme 2008), measured as having performed a home-based screening for blood in stools sent by mail by the NHS in the last two years. The bowel cancer screening program is an NHS-based program aimed at all individuals aged between 50 and 74 years old registered with a GP[29] in which all eligible individuals receive every two years a screening kit with tools and instructions in order to conduct a home-based screening for blood in stools. After the age of 74, the program continues to send the screening package only upon demand (the user must request the kit by calling). (3) Breast cancer screening, measured as whether the individual (only women) attended a screening visit after being invited (this includes non-symptomatic, only screening cases) to have a mammogram performed by the NHS Breast Screening Programme (NHSBSP) (NHS Breast Screening Programme 2005) during the last three years. The breast cancer screening program is an NHS-based program aimed

[29] GP Stands for General Practitioner and it is a physician that represents the point of care for all residents of England attending a consult with the National Health Service.

at all women registered with a GP between 50 and 70 years old. Unless they are symptomatic, they are invited to attend a mammogram for breast cancer screening every three years while in the eligible age range. Importantly, data on breast and bowel cancer screening are only available in wave 6, so these two variables are only assessed using data from wave 6 and not the previous two waves. Table 4.2 presents the descriptive statistics of the outcomes of this study. Unfortunately, we cannot observe the reason for why the person did not attend the screening visit in the case of the two screening programs.

Table 4.2 Descriptive statistics for the dependent variables by wave

Dependent variables	Wave 2		Wave 4		Wave 6		Full sample		
	n	%	n	%	n	%	*n*	%	*p*
Number of cigarettes smoked per week									
0 cigarettes	5,521	89.41	5,808	91.78	5,672	92.18	21,795	90.93	
1-10 cigarettes	95	1.54	90	1.42	67	1.09	329	1.37	
10-20 cigarettes	163	2.64	140	2.21	134	2.18	577	2.41	0.05
20-40 cigarettes	288	4.66	290	4.58	239	3.88	1,067	4.45	
>40 cigarettes	108	1.75	0	0.00	41	0.67	200	0.83	
Attending bowel cancer screening in the last 2 years (+50 years old)									
Yes					2,240	47.37	2,720	44.28	<0.01
No					2,489	52.63	3,423	55.72	
Attending breast cancer screening in the last 3 years (50-70 years old)									
Yes					1,493	61.44	1,836	71.63	0.47
No					937	38.56	1,189	46.39	

Note: Each column displays the descriptive statistics of each of the independent variables. It includes participants aged 50 to 99 for the case of number of cigarettes per week and bowel screening. Women between 50 and 70 years are included for the case of breast cancer screening. The variable for mammogram and bowel screening is only available for wave 6. The number of cigarettes is used as a continuous variable in the analyses but presented here as categorical. Roll-ups are included in the analysis as the equivalent of half a cigarette.

4.3.3 Independent variables

The allostatic load variable comprises the main independent variable. We discuss this variable first, and then we describe the control variables.

4.3.3.1 Allostatic load

A recurrent problem to study chronic stress in the general population has been its challenging measurement. Stress has been traditionally measured by self-report (Robert Wood Johnson Foundation/Harvard School of Public Health 2014) by using questionnaires (Gardner and Oswald 2004), or through proxies such as being a war veteran (Costa and Kahn 2010). Self-perception of stress is commonly masked by several factors, including coping strategies and recency bias, which can confound any self-reported measurements of chronic stress. The allostatic load metric provides information on the physiological markers and effects of a sustained stress response. The allostatic load is increasingly being used, especially in epidemiological and social sciences research, to recognize not only the role of stress on different conditions and behaviors, but also to measure it in a more accurate way (Gardner and Oswald 2004; Kirschbaum et al. 1999; Read and Grundy 2014).

In this research study, the allostatic load measure has been taken as the approach to measure stress given that it is a valid and reliable, well-accepted and measurable method (Goldman et al. 2005; Wippert et al. 2014; Teresa E. Seeman et al. 2004; Howard and Sparks 2016; T. E. Seeman, Singer, et al. 1997; Gersten 2008). The allostatic load index has been widely used to measure chronic stress levels because it shows correlation with steady levels of stress response in different validation studies (Bruce S. McEwen 2000; T. E. Seeman, McEwen, et al. 1997). Most of the allostatic load literature defines an abnormal biomarker as any with a value above the 75th

percentile (or otherwise below the 25th percentile for some specific biomarkers) of the empirical distribution of that biomarker in the population. Each abnormal biomarker adds up one unit towards the allostatic load metric. Studies using the allostatic load metric tend to be heterogeneous on the number and the type of biomarkers that are used across different studies. Which biomarkers are used often depends on the availability of those biometric markers in different surveys; however, the findings have proven to be robust across different indexes (Juster, McEwen, and Lupien 2010).

In this study, the cut-off points to determine an abnormal biomarker are similarly set at the value corresponding to the 75th percentile of the distribution of the biomarker in the population stratified by sex. The reason to stratify the estimation of abnormal values for each biomarker by sex is intended to avoid penalizing one sex category when both men and women are assessed using the same thresholds. It is for this reason that we decided to stratify the thresholds, which are presented in table 4.3.

Table 4.3 Cut-off points for determining an abnormal biomarker

	Wave 2		Wave 4		Wave 6	
	Female	Male	Female	Male	Female	Male
Systolic blood pressure (mm Hg)	151.0	150.0	146.0	148.0	145.0	146.0
Diastolic blood pressure (mm Hg)	83.0	84.0	82.0	83.0	82.0	82.0
HbA1c (mmol/mol)*	5.7	5.8	6.0	6.0	42.0	43.0
BMI	31.1	30.2	31.4	30.5	31.4	30.6
Waist (cm)	98.5	108.5	100.8	109.4	100.2	109.2
Cholesterol (mmol/L)	6.9	6.3	6.6	6.0	6.6	6.0
C-Reactive Protein (mg/L)	3.5	2.9	4.3	3.6	3.5	2.9
Fibrinogen (g/L)	3.7	3.5	3.7	3.6	3.3	3.2

Note: The cut-off points are estimated at the value of the 75th percentile of the population distribution of each biomarker. *For waves 2 and 4, the measurement unit for HbA1c is percentage whereas for wave 6 is mmol/mol.

The allostatic load metric is an empirical tool that signals the neuroendocrine response of the body to stress. Biomarkers used to build the allostatic load metric mostly take into account five dimensions of the stress response. This survey has been used in the past to carry out research on allostatic load at the population level (Read and Grundy 2014). Here we list the biomarkers used in this study by dimension: 1) Cardiovascular activity, measured through the systolic and diastolic blood pressure. 2) Glucocorticoid activity is obtained by measuring the levels of total cholesterol, glycated hemoglobin, BMI and the waist diameter. 3) Finally, fibrinogen and the C-reactive protein is a proxy for inflammatory and immune activity. (Read and Grundy 2012).

External stressors, individual factors and the behavioral responses to those factors determine the level of allostatic load of an individual (B. S. McEwen 1998). These three aspects of the response to stress affect the four dimensions of factors key for successful ageing: physical, cognitive, emotional, and behavioral factors (Rebok, Parisi, and Kueider 2014).

These factors module the physiological response that is observed as an increased allostasis rate and therefore, a higher allostatic load. In this paper, the number of abnormal biomarkers (out of eight) was defined as the allostatic load indicator. Even though there is discussion about whether each of the allostatic load biomarkers should have differential weightings, evidence shows that the simple count of abnormal biomarkers is highly predictive of a wide range of outcomes (Read and Grundy 2012; Seplaki et al. 2005). Similarly to prior work, eight different biomarkers are used to estimate the allostatic load across the three waves (Juster, McEwen, and Lupien 2010).

The first construct validity study using the allostatic load measure was made by Seeman et al (T. E. Seeman, Singer, et al. 1997) in which they showed the gradient existing between the allostatic load measure as a proxy for stress and the cognitive and functional scores of a sample of seniors in the US. Factor analysis has been conducted with the allostatic load measure, showing that it is comprised by one single underlying factor (Howard and Sparks 2016), evidencing the unidimensionality of the measure when being used to measure chronic stress at the population level. In terms of predictive validity, the allostatic load has proved to predict functionality, mortality, and cognition (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2002; Crimmins, Kim, and Seeman 2009; Goldman et al. 2006). One study found that 35.4% of the variance in mortality risk attributable to education is captured by the effect of the allostatic load (Teresa E. Seeman et al. 2004).

Regarding reliability of the allostatic load measure, one study found that the test-retest reliability of allostatic load comparing it with the Trierer Inventory of Chronic Stress produces an intraclass correlation coefficient of 0.89 (Wippert et al. 2014). Internal consistency studies show that the Alpha internal consistency reliability score of the allostatic load measure reaches 0.79 (Goldman et al. 2005).

A literature review carried out by Juster et al (Juster, McEwen, and Lupien 2010) shows that the body of research on allostatic load has produced reliable and consistent results ranging from assessing the stress caused by racial differences (Geronimus et al. 2006) to the effectiveness of anxiolytic drugs on cognition and stress (Soria et al. 2015).

Wave was include as a control variable. All control variables are self-reported and classified into the following vectors:

4.3.3.2 Demographic variables

Sex: Allostatic load as well as the demand for prevention might differ by sex as shown in prior research (Seplaki et al. 2004).

Age: Allostatic load can vary over time in the same individual. To control for this fact, the variable age will be included in a linear form as most of literature uses it (Crimmins et al. 2003).

Government Office Region: This variable accounts for the nine administrative regions of England, which can be representative of differences on health outcomes and deprivation during childhood (Woods et al. 2005). Despite the fact that we do not have the location of the respondent during her childhood, this variable might be relevant because it provides a proxy for differences in the current environment related to geographical variation, which also affect chronic stress levels (Dahl 2004).

4.3.3.3 Socioeconomic variables

Marital status: This is an important variable because prior research shows evidence on the relationship of marital status with allostatic load levels and preventive behavior (Cramm and Nieboer 2012; Gersten, Dow, and Rosero-Bixby 2010). With the aim of simplifying the analysis, a dichotomous variable was built defining whether the individual lives with a partner (married, living with a permanent partner) or not (never married, widowed or divorced).

Belonging to a household with wealth higher than £35,000: Wealth was measured as a dichotomous variable signaling whether the household wealth where the respondent lives is located above or below the median of wealth estimated (£35,000). Similar to the work of Hamer

et al (Hamer, de Oliveira, and Demakakos 2014; Marmot et al. 2003), wealth was estimated as a monetized measure (in Great Britain Pounds) of the total household wealth net of household debt and excluding the participant's value of the home (with or without mortgage) and physical wealth such as artwork or jewelry. Different from what was done in Hamer et al study (Hamer and Stamatakis 2013), we included financial assets such as savings, and business assets for considering them an important part of the total wealth variable. Wealth is a more appropriate variable to measure the socioeconomic conditions of the respondent as seniors often count only partially on regular sources of income. Prior research has found there is a linear relationship of wealth with preventive behavior and allostatic load (Dowd and Goldman 2006; Evans and Schamberg 2009). Results in graphs were also shown comparing the top and lowest decile of the distribution of the wealth variable.

Education level: Education is found to be correlated with allostatic load in prior research studies (Kubzansky, Kawachi, and Sparrow 1999). In the population that pertains to this research, education is relatively exogenous as the educational choices were taken several decades before. This variable was included in its original format which is a variable with eight categories (no qualification, foreign, other, NVQ1 (pre-higher diploma), NVQ2 (higher diploma), NVQ3 (progression diploma), NVQ4 (Certificate of higher education), and NVQ5 (Postgraduate certificate) equivalent to the National Vocational Qualification (NVQ1-5) official categorization of England (UK Government 2015).

Retirement: We included a binary variable accounting for whether the respondent reported to be retired at the time of the survey, as we anticipate this can be an important factor of stress. This is a dichotomous variable and does not account for different retirement statuses.

Size of the household: The size of the household is an important variable that is often used in research carried out in senior populations because it proxies the social capital and the family support of the respondent (Trujillo, Hyder, and Steinhardt 2011).

4.3.3.4 Health and cognition variables

Number of comorbidities: Comorbidities are an important determinant of preventive behavior (Seplaki et al. 2005; S. L. Szanton et al. 2009). We included a variable accounting for the number of comorbidities that the individual has at each survey as this is a recognized proxy measure for the degree of comorbidity of the individual (Wolff, Starfield, and Anderson 2002). This measure includes the comorbidities that are deemed to produce the higher burden of disease in the United Kingdom (C. J. L. Murray and Lopez 2013): angina, myocardial infarction history, congestive failure, stroke history, lung disease or cancer. We also included the following comorbidities: high blood pressure, diabetes, high cholesterol, dementia, and arthritis. They were also included given its high prevalence and burden. These conditions were all self-reported and were summarized in a variable that summed up the number of these conditions present for each individual at each wave.

Difficulty walking 100 yards: This variable accounts for health issues that prevent the person to walk 100 yards and that would be expected to last more than 3 months. This constitutes a control variable for the level of disability experienced by the individual.

Cognitive skills: Allostatic load affects cognitive skills according to previous studies (Seplaki et al. 2005). As a consequence, cognitive and mental function was incorporated using two memory indices from the ELSA survey that have been used and validated in other population-level surveys (Ofstedal, Fisher, and Herzog 2005) for measuring one dimension of cognition. The first one is the date recall test, which is a 4-item variable accounting for recall of the current date (day, day of the week, month and year). The second one is the word recall test, which result is the sum of the number of words recalled immediately and after a delay (0 to 10 each for a total of 20).

4.4 Empirical strategy

Assessing the relationship between allostatic load and preventive behavior entails a challenge as the specification is not straightforward and there is room for endogeneity from two main sources. First, there are endogenous factors that can affect both preventive behavior and stress. For example, having chronic conditions that cause stress and also reduce the ability of the respondent to carry out preventive activities might confound the causal relationship between stress and preventive behaviors in either a positive and a negative direction. Having other comorbidities can increase the level of stress in a given individual, but it also can increase preventive activities as the marginal cost of producing prevention for the next unit of health is lower (Dow, Philipson, and Sala-i-Martin 1999); or alternatively, the marginal cost of producing prevention when the level of depreciation of health hits a point of no return might be too high. These important confounding factors can be controlled for by including the vector of health variables in the equation. However, there is another source of endogeneity that cannot be addressed the same way. On the one hand, diabetes and hypertension themselves can cause an increase in the allostatic load metric. For example, diabetes can increase the levels of glycated hemoglobin as well those individuals with hypertension would have increased blood pressure levels; but also disease itself can increase stress factors. Chronic conditions are related to inflammation and immune response, which also is reflected by allostatic load indicators such as fibrinogen or C reactive protein (Read and Grundy 2012).

Given the two-way causality path that can be observed in the relationship between allostatic load and preventive behavior, it is necessary to find an identification strategy that can take into account the endogeneity issue. In this research, an instrumental variables model is set up in order to attempt the identification of the causal effect of stress in our set of preventive behavior outcomes.

$$(1)\ \ Allostatic\ load_{it} = \alpha_i + \gamma_1 Z_{it}$$

$$(2)\ \ Preventive\ behavior_{i6} = \alpha_i + \widehat{\beta_1} Allostatic\ load_{it} + \ \beta_2 Demog_{it} + \beta_3 SES_{it} + \beta_4 Health_{it}$$

for individual i at wave t using instruments Z.

Equation 1 shows the first stage of the instrumental variables estimation (see Table 4.4) where the allostatic load metric is estimated using the instruments and all the covariates. In the second part, the estimated value of the first equation is introduced in a regression to assess the effect that the allostatic load metric has on preventive behavior. The set of instruments comprise 1) the perception of the respondent of whether she feels or not that has had trouble managing her finances, and 2) whether she has had a highly stressful event in her life. The former instrument is justified since financial concerns constitute a source of stress (Mental Health Foundation 2013), but such concern should not be a cause of reduced preventive behavior. As mentioned before, an argument could be made that the correlation between both instruments could be related to physical activity through risk-aversion; however, stress has been found to modulate risk-taking behavior (Porcelli and Delgado 2009; Mann 1992; Trimpop 1994) . This implies that changes in risk-taking behavior that affect physical activity and financial concerns would be the actual behavioral signal of stress, our mediating variable. Another argument could be made that some preventive behaviors are sensitive to financial constrains such as smoking cigarettes or exercising in a gym.

Table 4.4. Linear regression on the effect of the instruments on the allostatic load measure

Allostatic load	Coeff	St. Error	***p***
Economic difficulties (Instrument 1)	0.09	0.03	<0.01
Stressful episodes (Instrument 2)	0.14	0.03	<0.01
Age	-0.01	0.00	<0.01
Sex	0.09	0.03	<0.01
Region			
North-East	Ref	Ref	Ref
North-West	0.02	0.06	0.69
Yorkshire and the Humber	0.07	0.06	0.19
East Midlands	0.07	0.06	0.24
West Midlands	0.06	0.06	0.32
East of England	0.01	0.06	0.81
London	-0.01	0.06	0.93
South-East	-0.01	0.05	0.87
South-West	0.07	0.06	0.18
Marital Status (REF: Living without a partner)	-0.07	0.03	0.02
Retired	0.08	0.03	0.01
Total household wealth (Tens of thousands GBP)	0.00	0.00	0.15
Education			
No qualification/other	Ref	Ref	Ref
Foreign	-0.14	0.05	<0.01
NVQ1	-0.13	0.06	0.03
NVQ2	-0.18	0.04	<0.01
NVQ3	-0.22	0.05	<0.01
NVQ4	-0.27	0.04	<0.01
NVQ5	-0.47	0.04	<0.01
Size of the household	-0.01	0.02	0.41
Number of comorbidities	0.16	0.01	<0.01
Cognitive test (Word recall)	-0.01	0.03	0.82
Cognitive test (date recall)	-0.01	0.00	0.10
Difficulty walking 100 yards	0.48	0.05	<0.01
Wave 2	Ref	Ref	Ref
Wave 4	-0.18	0.03	<0.01
Wave 6	-0.21	0.03	<0.01
Constant	2.53	0.18	<0.01

Note: Regression of the full set of variables and the instruments on the allostatic load measure comprising the first stage of the two-stage instrumental variables regression. Taylor linearized standard errors displayed. N= 17279; F=34.58, R Squared 0.0519

However, these examples do not capture the entire set of options to engage in preventive behavior. It is possible to switch from cigarettes to roll-ups which are less costly and also tobacco has an inelastic pattern of consumption (Chaloupka et al. 2002); therefore, any change in the financial ability to purchase tobacco is expected to be low. Regarding the screening activities in the UK, they are free of charge through the National Health Service (NHS), therefore they are not expected to be affected by income. This variable is defined as a binary variable if the respondent considers she manages her finances: (0) “quite well” or “very well”, or (1) “get by alright”, “don't manage very well”, “has some financial difficulties” or “has severe financial difficulties”.

The second instrument we use is being exposed to a highly stressful event during her life. This variable has been used in the past as a proxy for stress in previous research (Costa and Kahn 2010), and can be a cause of chronic stress due to the trauma experienced early during the childhood, which has been proved in previous research that is correlated with higher levels of allostatic load later in life (Turner, Thomas, and Brown 2016; Tomasdottir et al. 2015). Individuals having experienced a stressful event are the ones who report any of the following events: 1) When aged under 16, parents who drank excessively, took drugs or had mental health problems; 2) Having had a husband, wife, partner or child who has been addicted to drugs or alcohol; 3) Ever being a victim of sexual assault (including rape or harassment); 4) Other than in war or military action, having ever witnessed an accident or violent act in which someone was killed or seriously wounded; 5) Having ever provided long-term care to a disabled or impaired relative or friend; and 6) Having ever experienced severe financial hardship. As mentioned before, changes in risk-taking behavior from these experiences would reflect changes in behavior in physical activity and smoking only through stress.

4.4.1 Estimation

For each of the three preventive behavior outcomes, we conducted a linear regression model for each outcome with two different specifications: 1) pooled linear regression where we assumed exogeneity of the allostatic load measure, and 2) an instrumental variables design where we instrument the allostatic load metric using the two instruments described above. These models are presented in order to allow the reader to observe the changes in the coefficients and standard errors when using different sets of variables, and when changing the exogeneity assumption of the allostatic load measure. Table 4.5 presents the coefficients and Taylor linearized standard errors of the allostatic load variable for each preventive outcome. The full regression results for all the variables are available in appendix 4.1

4.5 Robustness checks

Since we are using an instrumental variables analysis, we need to test the validity of our instruments. Appendix 4.2 presents the robustness checks carried out on the instruments. We performed a Haussman test to assess the null hypothesis that the relationship between allostatic load and the outcome is exogenous, which was rejected, confirming that the regression is endogenous and therefore it requires an alternative identification strategy, such as an IV design. The inclusion restriction test assesses the null hypothesis that the instruments have no impact on allostatic load. We rejected the null hypothesis confirming that the instruments are strong enough. The overidentification test evaluates the null hypothesis that the specification is not overidentified. We did not reject the null hypothesis that the instruments are overidentified, strengthening the argument that the instruments are valid. All tests included all the control variables.

4.6 Results

4.6.1 Allostatic load and tobacco consumption

The allostatic load measure is positively related to the number of cigarettes smoked (or the cigarette-equivalent of roll ups) per week in both the pooled regression and the instrumental variables results. We found that the baseline levels of smoking increase by 317% in our instrumental variables estimation with the increase of one unit of the allostatic load variable, which were underestimated (but still significant) in the pooled regression when the allostatic load is assumed to be exogenous (table 4.5). These results suggest that increases in allostatic load increase the levels of tobacco consumption. The magnitude of change in tobacco consumption is very significant and should be a concern for policy-makers and clinicians. Individuals with higher levels of stress are at risk of increasing their tobacco consumption and as such, they should be targeted by more intensive prevention anti-smoking programs. The increase in tobacco consumption associated with the increases in allostatic load might partially explain the higher levels of cardiovascular events associated with higher allostatic load levels in previous literature (Juster, McEwen, and Lupien 2010).

In order to account for potential time-correlated errors in the panel data that might decrease the standard errors and therefore, increasing the risk of type 1 error, robustness checks were performed. Both a lagged IV model and a Generalized Estimating Equations model (GEE) were performed. Both strategies reveal that the results remain significant. However the coefficient using the GEE estimation dropped at an increase of 7%. These results are available in table 4.6.

Table 4.5 Effect of allostatic load on preventive outcomes for pooled and instrumental variable models

Dependent variable	n	Mean	Coeff	Relative effect	SE	*p*
Number of cigarettes smoked per week						
Pooled regression	18,826	3.43	0.41	12%	0.06	<0.01
IV	17,279	3.43	10.92	318%	2.18	<0.01
Attending bowel screening in the last 2 years						
Pooled regression	4,641	0.47	-0.01	-3%	0.00	<0.01
IV	4,641	0.47	-0.17	-36%	0.09	0.05
Attending breast cancer screening in the last 3 years						
Pooled regression	1,749	0.61	-0.01	-2%	0.01	0.05
IV	1,749	0.61	-0.18	-29%	0.11	0.10

Note: Results including controls for the following variables: Demographic (age, sex, and region in England), socioeconomic (Total household wealth in tens of thousands GBP, marital status, retired, education, and size of the household), health (number of comorbidities, ability to walk 100 yards, cognitive test for date recall, cognitive test for word recall), and wave. The instruments used are: number of stressful episodes and perceived ability to manage her own finances. Screening variables are only available for wave 6. Regressions for breast cancer screening are limited to women between 50 and 69 years old. The variable for cigarettes is treated as a continuous variable and include cigarettes and the cigarette-equivalent for roll-ups. Taylor linearized standard errors displayed.

Table 4.6 Robustness checks on the effect of allostatic load on tobacco consumption

Dependent variable	n	Mean	Coeff	Relative effect	SE	***p***
Number of cigarettes smoked per week						
Lagged IV	8,720	3.43	12.26	357%	5.07	0.02
Generalized estimating equations	17,279	3.43	0.24	7%	0.06	<0.01

Note: Results including controls for the following variables: Demographic (age, sex, and region in England), socioeconomic (Total household wealth in tens of thousands GBP, marital status, retired, education, and size of the household), health (number of comorbidities, ability to walk 100 yards, cognitive test for date recall, cognitive test for word recall), and wave. The instruments used are: lagged number of stressful episodes and perceived ability to manage her own finances. The variable for cigarettes is treated as a continuous variable and include cigarettes and the cigarette-equivalent for roll-ups. Taylor linearized standard errors displayed.

4.6.2 Allostatic load and screening

We find that the allostatic load has a negative effect on the demand for the two screening programs of our study. Our results using instrumental variables show that every additional unit in the allostatic load measure is related to a reduction in the demand for breast cancer screening of around 29% from the average screening rate, whereas it decreases the average levels of bowel cancer screening by around 36%.

These results are important because they suggest that individuals with higher levels of stress are less likely to uptake screening programs. Properly identifying individuals with higher levels of stress at the GP consult might increase the uptake of these programs by patients with higher levels of chronic stress. These individuals would be more likely to attend if they are for example, derived to a more intensive program while the source of high stress remains.

4.7 Discussion

To our knowledge, this is the first study that assesses empirically in a population-based survey the effect that stress has on preventive behavior. In this study, we used an instrumental variables design, an accepted econometric approach to infer causality in observational data to evaluate the effect that a proxy variable for chronic stress, the allostatic load measure, has on preventive behavior. We assessed three different preventive behaviors: Smoking, breast cancer screening and bowel cancer screening in a survey of respondents older than 50 in England who are followed up for three waves (8 years).

We found that one additional abnormal indicator of the allostatic load metric is related to an increase in smoking of 318% times the baseline frequency of smoking. We also found that one additional unit in the allostatic load indicator is related to a reduction of 29% of the demand for the NHS Breast Cancer Screening Program and of 36% on the demand for the NHS Bowel Cancer Screening Program.

Previous studies have shown that higher levels of allostatic load are related to higher rates of cognitive decline among seniors (Karlamangla et al. 2005), a higher likelihood of impaired decision-making processes, and a reduced ability to act as a consequence of its effect on specific cognitive functions such as performance in tasks and working memory (Diamond 2005; Evans and Schamberg 2009). Higher levels of allostatic load have also shown to decrease positive responses to the environment (Lindfors, Lundberg, and Lundberg 2006), functionality (Kado et al. 2005; Karlamangla et al. 2002; Seplaki et al. 2004), and self-efficacy (Bandura 2010). Jayanti and Burns (Jayanti and Burns 1998) test empirically a model in which self-efficacy, is a key modulator of the path between health motivation and actual behavior. Bandura (Bandura 1991) states how self-efficacy is key on determining personal agency and self-regulation, which in turns affects the level of engagement in preventive activities. Previous research has shown that changes in the demand for preventive care can be affected by causes other than price (Goodwin and Anderson 2012)

Prior literature has shown how cognitive skills, which are affected by stress, specifically affect preventive behavior such as the use of sunscreen (Craciun et al. 2012), and vaccination, mammography or non-smoking (Avitabile, Jappelli, and Padula 2011).

Unfortunately, few economic studies containing conceptual models in economics for preventive behavior, have mentioned the role of stress (Kenkel 2000; Powell and Chaloupka 2009), and usually it is done in indirect ways such as including stress as a mediator of the relationship between education and health (Cutler and Lleras-Muney 2006; Trujillo and Fleisher 2013), or through proxies such as depression (Gitto, Noh, and Andrés 2015), or war (Costa and Kahn 2010). However, previous work in the links between education and health provides insights to the mediating factors associated with lower levels of preventive activities. Those mediating factors, specifically, cognitive skills can be affected through different mechanisms, such as stress, implying that stress can be a determinant of the engagement in preventive activities.

Seminal work in both psychology (Bandura 1991) and economics (Grossman 1972) agree that individual's current behavior is based, to some extent, on their time preferences and future expectations. Individual time preferences can be affected by stress, inducing myopic responses in individuals. Policy alternatives that steer the default option towards preventive behavior, making easier for people to behave as if they were not myopic, might increase the demand for these programs, especially among individuals with higher levels of chronic stress. In chapter 2 of this dissertation, we confirmed that higher levels of allostatic load are related to reduced scores in cognitive tests[30].

Our research contributes to the existing literature by suggesting that chronic stress might affect preventive behavior, and needs to be taken into account by both policy-makers designing prevention policies, and also by clinicians who assess patients facing higher levels of chronic stress.

Prior studies have shown that the psychosocial characteristics of the individuals affect the uptake of screening programs and that aspects such as social support and coping strategies determine the level of uptake of screening programs (Gili et al. 2006). It is possible that the mechanism through which coping strategies and social support increase the uptake of preventive programs is through a reduction of chronic stress.

Our results show that the uptake of a screening program can be affected by chronic stress levels. Screening programs that identify individuals with higher levels of stress might be more likely to increase their uptake by providing them with more support. (Wilkinson 2008). One key issue is identifying individuals with higher levels of stress who would benefit from being targeted by more intensive preventive programs. In chapter 2 of this dissertation, some factors related to higher levels of allostatic load were described. Generally, individuals in more vulnerable conditions, living alone, less healthy, and living in less affluent households are more likely to have higher levels of allostatic load. As a consequence, more intensive preventive programs targeting and

[30] Chapter 2 corresponds to the first aim of this dissertation

nudging the default options for individuals belonging to these groups, might increase their uptake, and therefore constitute a potential public health alternative. It needs to be said that the effect of providing excessive support for seniors with lower levels of stress is not known. Previous experience in research in memory has shown that too much environmental support can be deleterious in the long term (Lindenberger and Mayr 2014), and it is precisely for this reason, as well as costs and capacity, that targeting rather than widespread intensive programs are likely to be the best alternative.

Appendix 4.1

OLS regression on the effect of the allostatic load measure on three preventive outcomes

Allostatic load	Number of cigarettes smoked per week			Attending bowel screening in the last 2 years			Attending breast cancer screening in the last 3 years		
	Coeff	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***
Allostatic load	10.92	2.18	<0.01	-0.17	0.09	0.05	-0.16	0.10	0.12
Age	-0.10	0.03	<0.01	-0.03	0.00	<0.01	-0.01	0.00	0.01
Sex	-0.11	0.37	0.77	-0.02	0.02	0.32			
Region	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
North-East	-0.49	0.80	0.54	-0.06	0.04	0.12	-0.02	0.06	0.74
North-West	-0.77	0.79	0.33	-0.10	0.04	<0.01	-0.03	0.06	0.62
Yorkshire and the Humber	-1.38	0.78	0.08	-0.06	0.04	0.09	-0.04	0.07	0.54
East Midlands	-0.77	0.73	0.29	-0.05	0.03	0.17	0.07	0.07	0.34
West Midlands	0.19	0.81	0.82	-0.12	0.04	<0.01	0.06	0.06	0.33
East of England	-0.29	0.71	0.68	-0.09	0.04	0.01	-0.04	0.06	0.46
London	-1.52	0.75	0.04	-0.08	0.03	0.02	-0.05	0.06	0.44
South-East	-0.92	0.43	0.03	0.08	0.02	<0.01	0.02	0.03	0.43
South-West	-1.35	0.41	<0.01	0.09	0.02	<0.01	0.03	0.03	0.38
Marital Status (REF: Living without a partner)	0.00	<0.01	0.51	0.00	0.00	0.67	0.00	0.00	0.01
Retired	-0.15	0.81	0.85	-0.01	0.04	0.73	-0.19	0.08	0.02
Total household wealth (Tens of thousands GBP)	-0.48	0.93	0.61	0.02	0.04	0.58	-0.08	0.08	0.36

Note: Results of the coefficient of the allostatic load metric regressed using two-stage linear regression with instrumental variables on each of the three preventive behavior outcomes. Screening variables are only available for wave 6. Regressions for breast cancer screening are limited to women between 50 and 70 years old as that is the population targeted by the NHS Breast Cancer Screening Program. The variable for cigarettes is treated as a continuous variable and include cigarettes and the cigarette-equivalent for roll-ups. Taylor linearized standard errors displayed.

Appendix 4.1 (cont.)

OLS regression on the effect of the allostatic load measure on three preventive outcomes (cont.)

Allostatic load	Number of cigarettes smoked per week			Attending bowel screening in the last 2 years			Attending breast cancer screening in the last 3 years		
	Coeff	**SE**	***p***	**Coeff**	**SE**	***p***	**Coeff**	**SE**	***p***
Education									
No qualification/other	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Foreign	0.10	0.92	0.92	-0.01	0.05	0.83	-0.13	0.08	0.11
NVQ1	0.32	0.87	0.71	0.02	0.04	0.59	-0.18	0.08	0.03
NVQ2	1.15	1.11	0.30	-0.05	0.05	0.33	-0.22	0.08	0.01
NVQ3	-0.14	0.21	0.50	-0.04	0.01	<0.01	-0.01	0.02	0.49
NVQ4	-1.66	0.39	<0.01	0.03	0.01	0.05	0.02	0.02	0.31
NVQ5	-3.39	1.31	0.01	0.01	0.05	0.82	0.08	0.11	0.46
Size of the household	-0.14	0.21	0.50	-0.04	0.01	<0.01	-0.01	0.02	0.49
Number of comorbidities	-1.66	0.39	<0.01	0.03	0.01	0.05	0.02	0.02	0.31
Difficulty walking 100 yards	-3.39	1.31	0.01	0.01	0.05	0.82	0.08	0.11	0.46
Cognitive test (date recall)	-0.30	0.36	0.41	0.02	0.02	0.21	0.11	0.03	<0.01
Cognitive test (word recall)	0.00	0.06	0.95	0.01	0.00	0.03	0.00	0.00	0.94
Wave 2	Ref	Ref	Ref						
Wave 4	1.72	0.59	<0.01						
Wave 6	1.77	0.65	0.01						
Constant	-5.57	5.86	0.34	2.97	0.25	<0.01	1.21	0.38	<0.01

Note: Results of the coefficient of the allostatic load metric regressed using two-stage linear regression with instrumental variables on each of the three preventive behavior outcomes. Screening variables are only available for wave 6. Regressions for breast cancer screening are limited to women between 50 and 70 years old as that is the population targeted by the NHS Breast Cancer Screening Program. The variable for cigarettes is treated as a continuous variable and include cigarettes and the cigarette-equivalent for roll-ups. Taylor linearized standard errors displayed.

Appendix 4.2

Instrumental variables tests by preventive outcome

	Exogeneity test (Haussman)	Inclusion restriction test	Over-identification test
Number of cigarettes smoked per week	<0.01	<0.01	0.24
Attending bowel screening in the last 2 years	<0.01	<0.01	0.76
Attending mammogram screening in the last 3 years	<0.01	<0.01	0.98

Note: Results of the Haussman test to assess the null hypothesis that the relationship between allostatic load and the outcome is exogenous. The inclusion restriction test assesses the null hypothesis hat the instrument have no impact on the allostatic load. The overidentification test evaluates the null hypothesis that the specification is not overidentified. All tests included the control variables: Demographic (age, sex, and region in England), socioeconomic (Total household wealth in tens of thousands GBP, marital status, retired, education, and size of the household), health (number of comorbidities, ability to walk 100 yards, cognitive test for date recall, cognitive test for word recall), and wave. The instruments used are: number of stressful episodes and perceived ability to her own finances. Screening variables are only available for wave 6. Regressions for breast cancer screening are limited to women between 50 and 70 years old as that is the population targeted by the NHS Breast Cancer Screening Program. The variable for cigarettes include cigarettes and the cigarette-equivalent for roll-ups.

5. Conclusions

This dissertation is focused on providing empirical evidence on the relationship of the allostatic load measure, as a proxy for chronic stress, with different demographic and socioeconomic characteristics, its consequences on preventive behavior and the extent to which a pension program can contribute to reduce its levels.

In the first paper (chapter 2) we study the characteristics of the English seniors who experience higher levels of allostatic load. We show how stress has important demographic and socioeconomic correlates. Chronic stress is associated with a higher incidence of chronic conditions. Higher allostatic load is more likely to be observed among people living alone and without a partner, which highlights the role of social support on experiencing chronic stress.

This paper shows that respondents living in less affluent households experience higher levels of allostatic load. Most research in inequalities focus on the financial dimension of living in poverty. This research provides evidence that inequalities actually have consequences in other dimensions, specifically chronic stress. This is important because chronic stress can constitute one of the mechanisms by which poverty is perpetuated over time and that the burden of chronic stress among seniors in England is disproportionally higher among the more vulnerable ones (Sarah L. Szanton, Gill, and Allen 2005).

In the second paper (chapter 3), we assess the effect of the state pension program in the levels of allostatic load among seniors in England. Social programs can help in reducing the levels of stress of their beneficiaries, comprising often unmeasured welfare gains from these programs, which are often not taken into account neither during the technical evaluations nor in the political discourse. This study provides evidence that suggests that becoming eligible for the UK state pension reduces the levels of allostatic load by between 11% and 17% among males living in less wealthy households with no measurable impact on the more wealthy ones. Our results also suggest that there is an effect on senior females living in less wealthy households who are also living alone. These findings provide evidence that chronic stress reductions might represent welfare losses that can be potentially addressed through social programs, and that are not usually accounted for in standard cost-benefit studies. Pension programs might reduce chronic stress, especially among male seniors living in less affluent households, and therefore reducing the higher burden of stress these individuals experience.

The third paper (chapter 4) tests the hypothesis that chronic stress among seniors can constitute a barrier to engage in preventive behavior. It studies the effect of the allostatic load in three different preventive behaviors using an instrumental variables design. The paper finds that the allostatic load measure is likely to reduce the engagement in preventive behavior, specifically increasing smoking, and reducing the demand for both breast cancer and bowel cancer screening. The paper discusses how preventive behavior might be affected by stress through its effects on self-efficacy

This dissertation attempts to bring the issue of chronic stress to the conversation in the public health field. Stress has been for long a neglected risk factor in public health, despite it has been related to higher incidence of diabetes (Crews 2007), cardiovascular disease (Sabbah et al. 2008; T. E. Seeman, Singer, et al. 1997), reduced cognition scores (Juster, McEwen, and Lupien 2010; Karlamangla et al. 2002), and all-cause mortality (Crimmins, Kim, and Seeman 2009; Goldman et al. 2006). Probably, the difficulty on measuring the magnitude and incidence of chronic stress at the population level is responsible for the fact that research on this topic using large population-based studies is sparse, and therefore, population-level interventions on stress have not been discussed. There is a growing trend to measure chronic stress through physiological biomarkers that signal either the stress response itself or the chronic consequences of that reaction. This set of biomarkers is commonly called allostatic load and comprises the level of 'wear and tear' of the body when the body responds chronically to stress (Juster, McEwen, and Lupien 2010; B. S. McEwen and Stellar 1993; T. E. Seeman, Singer, et al. 1997). This dissertation attempts to show the relevance of chronic stress among English seniors as a correlate of demographic, socioeconomic and health factors, as well as a potential causal barrier to engage in preventive behavior. Finally, it also attempts to measure the extent to which chronic stress can be affected by population-level interventions, such as the state pension, especially for those living in less affluent households.

In chapter 2 we present how the burden of stress disproportionally affects seniors living in more vulnerable conditions. This is a very important point because it implies that the differences of the burden of stress across wealth categories reflect just one more dimension in which income inequality affects less affluent individuals, and it also constitutes a pathway through which the cycle of poverty might be perpetuated. Prior studies have shown that adults who report having experienced childhood adversity are more likely to have higher levels of allostatic load during their adult lives (Shonkoff et al. 2012; Tomasdottir et al. 2015; Turner, Thomas, and Brown 2016). The higher levels of allostatic load in these adults might affect their decision-making processes. This can in turn adversely affect their financial (Agarwal et al. 2007), or health decisions, as it was shown in chapter 4 of this dissertation. The findings of this research dissertation contribute to the growing body of research that establishes the mediating role that other literature has suggested chronic stress might have on the link between socioeconomic conditions and health (Sarah L. Szanton, Gill, and Allen 2005).

5.1 Policy implications

In terms of population-level interventions that can help to curb the burden of stress, two contributions, one related to the health sector and the other one, extrasectorial, stand out of this research work. First, we provided evidence in chapter 3 that the state pension program reduces the allostatic load among seniors living in households with wealth levels lower than the median. This might imply that pension programs, and perhaps more generally other social programs that provide cash transfers to seniors, can reduce the burden of chronic stress, especially to those living in poverty and in vulnerable conditions. Consistent with the aims of the state pension of preventing poverty among the elderly, and considering the budget constraints the pension system in England faces with a broadening beneficiary base, perhaps a more efficient approach would be a combination of the original social insurance scheme proposed in the Beveridge report in 1942 and a combined means-tested approach that could better target vulnerable seniors in order to lift them from poverty. Other options could be the implementation of parallel cash transfer programs that provide income support for seniors living in poverty. As described, extra sectorial interventions to reduce chronic stress can contribute to reduce the burden of direct health and social care costs.

The second contribution on population-level interventions is on the design of screening programs. In chapter 4, we described the effect that chronic stress has on preventive behavior and particularly on the uptake of screening programs. Designing screening programs that identify individuals with higher levels of stress, and consequently target them with more intensive approaches, might improve the uptake of these programs and their effectiveness. The allostatic load has been associated with a reduction in scores for different cognitive skills and has been shown to affect decision-making processes, self-control and long-term planning (Diamond 2005; Evans and Schamberg 2009; Glanz, Rimer, and Viswanath 2008; Karlamangla et al. 2005; Lindfors, Lundberg, and Lundberg 2006; Muraven and Baumeister 2000; T. E. Seeman, McEwen, et al. 1997). We hypothesize that the effect of the changes in the levels of stress in the uptake of the program might be mediated by changes in the self-efficacy of these individuals. Therefore screening programs that identify and provide more support for individuals with risk factors for higher levels of stress (such as living alone) might improve their uptake and effectiveness.

More broadly, this dissertation and all the prior body of research on chronic stress emphasize that policymakers, clinicians, and the society in general needs to be aware of the effect that stress can have in our daily lives. Chronic stress is thought to be a direct cause of chronic disease (Bruce S. McEwen 2004; T. E. Seeman, Singer, et al. 1997; Seplaki et al. 2004). Chronic stress also can affect health through indirect ways by reducing the ability of individuals to engage in desirable behaviors, including health behaviors as suggested in this dissertation. Stress has been suggested as the potential mediator in the relationship between ethnic differences and chronic conditions (Jackson, Knight, and Rafferty 2010), and that also affects other aspects of behavior such as job control (Li et al. 2007) and socioeconomic status (Dowd and Goldman 2006; Worthman and Panter-Brick 2008).

All these reasons strengthen the argument that chronic stress is an important factor that needs the attention of the public health community. In the context of global and local factors becoming important sources of stress, which evidenced by the increasing rates of chronic conditions, mental disease and suicide (Ferrari et al. 2014), it is key that the public health community addresses this issue from a syndemic perspective, as it did with smoking and obesity in the past.

In this research work, we provide evidence of one current existing public program, the state pension, which can potentially yield previously unmeasured welfare gains to its recipients. When countries make decisions about making changes on public programs, often both the technical assessment as well as the political discourse do not take into account the impact of these unobservable factors down the line, which can cause financial and non-financial consequences. Therefore, cost-benefit evaluations of existing and new public programs should attempt to consider their non-monetary gains, as that might underestimate the benefits obtained from the program and affect its continuation or is scope.

A similar case has been faced by the public health community in the past. Research on the cost-effectiveness of interventions for infectious diseases has found that static models, not accounting for transmission tended to underestimate the effect of interventions in cost-effectiveness evaluations (Lugnér, Mylius, and Wallinga 2010). Similarly, if researchers and policy-makers are able to measure the full set of benefits accrued from social programs, including stress, the society would be able to take better and more informed decisions as to whether social programs should be implemented or continued.

The use of biomarkers represents a potential phase transition (Paina and Peters 2011) in the way that health and social services are provided by reducing reporting bias, and therefore facilitating a more reliable targeting of the populations for which any intervention yields a larger marginal social productivity (M. Goldman, Troisi, and Rexrode 2012) This dissertation contributes to such phase transition by evaluating the effect of a social program through biomarker measurement. One final caveat on using biomarkers in social policy are their immense ethical considerations, from the data collection to the data storage and analysis. These aspects are beyond the scope of this dissertation, but would likely require that the standards for using biomarkers in social policy are higher than those used in research, as in those cases identifiable information would be linked to particular individuals.

This dissertation expects to contribute to the broader research body on inequalities, showing that these can be also observed in the form of chronic stress, perpetuating the cycle of poverty by reducing the ability to act of those with higher levels of chronic stress. In addition, this dissertation provides evidence that social programs can yield welfare benefits that go beyond the usual cost-benefit analyses, and therefore that the benefits of the state pension program in England and potentially other social programs might be underestimated.

We expect to expand this research further to other countries, to measure the impact that different types of social programs have on stress, and to extend the scope of the effect of stress on behavior to other health and non-health behaviors including financial literacy among seniors.

5.2 Study limitations

This dissertation has several limitations that have to be highlighted. First, despite we have a nationally representative survey of seniors in England, because the biomarkers taken in each wave are only taken on individuals who are fit enough to undergo the biomarker measurements, we might be observing a healthier subgroup of this population. We actually only observe 78% of the survey population. This fact might affect our results by underestimating the effect sizes as those with presumptively higher levels of stress are not observed, leading to potential type 2 error (failing to reject the null hypothesis when the null hypothesis is false).

There is a substantial variability in the use of biomarkers in the allostatic load literature. We count with eight biomarkers that have been used and validated in previous studies; however, we do not have data on cortisol levels for this survey. More recently literature has started to use cortisol levels as one of the biomarkers of the allostatic load metric; however, a considerable body of evidence has been produced without this biomarker with consistent results (Juster, McEwen, and Lupien 2010). The consistency between the results found in this research and the previous literature is not surprising since the allostatic load metric is a unidimensional composite index of the level of the body's wear and tear, and its overall results are hardly influenced by one single biomarker.

Despite this dissertation uses standard econometric techniques to suggest causal relationships in observational data, no definite answers can be given as to the causality of the relationships. The conclusion of a causal relationship cannot be given by a single research study or a single technique. Knowledge on causal links is rather the cumulative process of creating a body of evidence that shows strong, robust and consistent results (Hill 1965). This dissertation attempts to contribute to such knowledge base.

6. References

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7. Curriculum Vitae (short version)

Andres I. Vecino Ortiz

EDUCATION

JOHNS HOPKINS UNIVERSITY SCHOOL OF PUBLIC HEALTH **Baltimore, MD. USA**
PhD in International Health - Health Systems *August 2011 – May 2016*

UNIVERSIDAD DE LOS ANDES **Bogotá, Colombia**
MSc in Economics *August 2007– September, 2009*
- Undergraduate core courses of economics taken between *August 2005 - August 2007*

PONTIFICIA UNIVERSIDAD JAVERIANA **Bogotá, Colombia**
Medical Doctor *June 1999 - June 2005*
- Clinical internship: Hospital Central do Maputo/Hospital Rural de Chicuque. Mozambique.
- Research internship: Universidad de los Andes, School of Medicine. Bogotá D.C. Colombia.

LANGUAGES

- **Spanish (native)**
- **English (fluent)**
- **Portuguese (intermediate)**

EXPERIENCE

JOHNS HOPKINS UNIVERSITY SCHOOL OF PUBLIC HEALTH **Baltimore, MD. USA**
Graduate Student *August. 2011 – May 2016*
- Development of a Lives Saved Tool for Chronic Conditions in five countries commissioned by USAID.
- Data management at the International Injury Research Unit in the Bloomberg Philanthropies Global Road Safety Program partnership.
- Cost-Effectiveness analysis for a set of child and maternal health interventions in Palestine - World Vision.
- Data analysis and project coordination for a worker's compensation consultancy project commissioned by AIG.
- Development of workshop material for the Dengue Vaccine Initiative.

JOHNS HOPKINS UNIVERSITY SCHOOL OF PUBLIC HEALTH **Baltimore, MD. USA**
Teaching assistant *August. 2011 – May 2014*
- Online Economic Evaluation I
- Online Health Economics I.
- Econometric methods for impact evaluation of health programs (advanced)
- Poverty, Economic Development and Health

INSTITUTE FOR HEALTH METRICS AND EVALUATION-UNIV. OF WASHINGTON Seattle, WA. USA.
Post-Graduate Fellow <u>See Link</u> *Sep. 2010 – August 2011*

COLUMBIA UNIV. MEDICAL CENTER/RESEARCH FOUNDATION MENTAL HYGYENE New York, NY. USA.
Research Scientist *Sep. 2008 – August 2010*

UNIVERSIDAD DEL ROSARIO-SCHOOL OF ECONOMICS **Bogotá, Colombia.**
Lecturer *July 2007– September 2008*
- Introduction to Microeconomics
- Microeconomic Analysis

UNIVERSIDAD DEL ROSARIO-SCHOOL OF ECONOMICS **Bogotá, Colombia.**
Young researcher *June 2006 – September 2008*

NATIONAL INSTITUTE OF CANCER - DIVISION OF RESEARCH, EPIDEMIOLOGICAL SURVEILLANCE, HEALTH PROMOTION AND PREVENTION. **Bogotá, Colombia.**
Physician in mandatory social service-Research Division *June 2005 – June 2006*

UNIVERSIDAD DEL ROSARIO-SCHOOL OF ECONOMICS **Bogotá, Colombia.**
Teaching Assistant *January 2001 – June 2004*

AWARDS AND FINANCIAL SUPPORT

HOPKINS CENTER FOR HEALTH DISPARITIES SOLUTIONS (HCHDS), JOHNS HOPKINS UNIVERSITY. BLOOMBERG SCHOOL OF PUBLIC HEALTH.

- Ethnic disparities in health: the case of African-Colombians. 02/2012-09/2012. Small grant (**Vecino AI**, Dedios-Sanguineti MC, Garcia-Jaramillo S).

NATIONAL DEPARTMENT OF SCIENCE, TECHNOLOGY AND INNOVATION, COLCIENCIAS.

- Scholarship Program "Becas Francisco José de Caldas". S*cholarship for PhD studies based on merit.* 08/2011-05/2016.

INTER-AMERICAN DEVELOPMENT BANK

- Preventive effort among diabetic patients in the context of an insurance-based health system: the Colombian experience. 06/2009-12/2009. Small grant (Trujillo A, **Vecino AI**, Ruiz F)

ACADEMIC REVIEW ACTIVITIES

PEER-REVIEW FOR RESEARCH JOURNALS

- Journal reviewer for Health Policy
- Journal reviewer for Alcohol
- Journal reviewer for Health Policy and Planning
- Journal reviewer for The American Journal on Addictions
- Journal reviewer for International Journal for Quality in Health Care
- Journal reviewer for Value in Health Regional Issues
- Journal reviewer for Bulletin of the World Health Organization
- Journal reviewer for International Journal of Environmental Research and Public Health

PEER-REVIEW FOR GRANT-FUNDED RESEARCH

- Reviewer for National Institute for Health Research-NIHR (London, United Kingdom).

REVIEWER FOR GRADUATE-LEVEL RESEARCH WORK

- Reviewer for thesis (Masters level). Universidad Autónoma de Manizales (Colombia)

SELECTED PUBLICATIONS

- **Vecino-Ortiz AI**, Bardey D, Castano-Yepes RA. *Hospital Variation in Cesarean Delivery: a Multilevel Analysis*. Value in Health Regional Issues. 2015; 8: 116-121.
- **Vecino-Ortiz AI**, Hyder AA. *Road safety effects of bus rapid transit (BRT) systems: A call for evidence*. Journal of Urban Health. 2015; 92(5): 940-946.
- **Vecino-Ortiz AI**, Bishai D, Chandran A, Bhalla K, Bachani A, Gupta S, Slyunkina E, Hyder AA. Seatbelt wearing rates in middle income countries: a cross-country analysis. Accident Analysis and Prevention. 2014; 71(2014):115-119.
- Hyder AA, **Vecino-Ortiz AI**. *BRICS: opportunities to improve road safety*. Bulletin of the World Health Organization 2014; 92(6): 423-428

- **Vecino-Ortiz AI**, Hyder AA. *The use of cost–benefit analysis in road assessments: a methodological inquiry*. Injury Prevention 2014; 20(1): 50-53
- **Vecino-Ortiz AI**, Trujillo A, Ruiz F. *Undetected diabetes in Colombia*. International Journal of Public Policy. International Journal of Public Policy 2012; 8(4/5/6): 362-373.
- Trujillo AJ, **Vecino-Ortiz AI**, Ruiz F, Steinhardt L. *Health Insurance Doesn't Seem To Discourage Prevention Among Diabetes Patients In Colombia.* Health Affairs 2010; 29(12): 2180-2188.
- **Vecino-Ortiz AI**. *Determinants of demand for antenatal care in Colombia*, Health Policy 2008;86(2-3):363-72.
- Rojas MP, **Vecino AI**. *Fraction of Cancer Attributable to Occupation in Developed Countries* (In Spanish). Revista Colombiana de Cancerología 2008; 12(2):89-105.
- **Vecino Ortiz AI**. *Accuracy in death certificates at Instituto Nacional de Cancerología. Colombia* (In Spanish). Revista Colombiana de Cancerología 2006; 10(3):170-182.

Selected working Papers

- **Vecino-Ortiz AI**, Lopez-Quintero C, Trujillo A. *Alcohol Excise Taxes and Alcohol Use Disorder: An Analysis Using Instrumental Variables.*
- Mindell JS, Moody A, **Vecino-Ortiz AI**, Alfaro T, Frenz P, Scholes S, Gonzalez SA, Margozzini P, Oliveira C, Sanchez Romero LM, Alvarado A, Cabrera S, Sarmiento OL, Triana CA, Barquera S. *Comparison of health examination survey methods in Brazil, Chile, Colombia, Mexico, England, Scotland and the USA.*

Books/Chapters

- **Vecino-Ortiz AI**, Dedios-Sanguineti MC, Garcia-Jaramillo S. Ethnic disparities in health: the case of Afro-Colombians. *Chapter for a book in:* TA. LaVeist (editor) Legacy of the Crossing: Life, Death and Triumph Among Descendants of the World's Greatest Forced Migration. Claybridge Media: Baltimore, MD. Forthcoming
- Jaramillo H, Lopera C, Gónzalez BE, **Vecino Ortiz AI**. *Impact of Financing Health Research 1970-2007* (In Spanish). Ed: Universidad del Rosario, Bogotá, D.C. Colombia.

Other selected collaborations

- Cristancho RA, **Vecino A**, Gallego, G. *Effectiveness, efficacy, safety and cost-effectiveness of Bupropion, Mirtazapine, Rivastigmine and Ziprasidone: evaluation of the evidence for Colombia* (In Spanish). Health Regulation Commission-Colombia, 2011.